PM_{10} SIP MODELING PROTOCOL
SALT LAKE COUNTY & UTAH COUNTY

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1.0 INTRODUCTION

The state of Utah is in the process of preparing a new State Implementation Plan (SIP) for PM_{10} in Salt Lake County and Utah County. The Wasatch Front Aerosol Modeling Protocol discusses the need for a new PM_{10} SIP, the characteristics of the PM_{10} problem in the Wasatch Front, and the modeling efforts which the Utah Division of Air Quality (DAQ) will undertake to address these PM_{10} issues. DAQ will seek assistance in this project from a consortium of contractors to assist in the modeling and control strategy development.

1.1 Background

The state of Utah developed a State Implementation Plan (SIP) for PM_{10} in the early 1990's which was approved by EPA in 1994. This SIP targeted Utah's historical problem with secondary particulate formation during wintertime inversions along the Wasatch Front. Although there have been no violations of the NAAQS in the nonattainment areas since the SIP was implemented, Utah's Department of Transportation expects that the next round of long-range transportation plans and transportation improvement plans, due in 2000 for Utah County and 2001 for Salt Lake County, will not be able to show conformity to the PM_{10} SIP. Much of this nonconformity is the result of EPA changes to mobile emissions models that were used to establish emission budgets in the current SIP. For this reason, and to fix elements of the current SIP which have created ongoing difficulties in implementation, the Utah Division of Air Quality (DAQ) has decided to create an entirely new PM_{10} SIP. It is possible that the work product could turn out to be a Maintenance Plan, in which case the nonattainment areas could be redesignated to attainment.

Modeling tools have advanced in the years between the development of the current PM_{10} SIP in the late 1980's and today. The existing SIP is based on receptor modeling and county-wide roll-back of PM_{10}, SO_2, and NO_x. In consultation with EPA Region VIII, DAQ has decided to base the attainment demonstration for this new SIP/Maintenance Plan on a grid-based aerosol modeling approach using UAM-AERO which will be corroborated by a speciated linear rollback. The attainment/maintenance demonstration would be based on the results of one or both of these models.

UAM-AERO, an urban-scale grid-based aerosol model developed by the California Air Resources Board will be used to analyze the airshed for either one or two historical episodes during 1996Because there have been no violations of the PM_{10} NAAQS since 1995, the historical episode does not represent excessive PM_{10} concentrations. In addition, availability of PM_{10} data is sparse in the 1990's due to relatively clean air quality during this time period. Since aerosol modeling is still in its infancy, relative to photochemical ozone modeling, guidance on model performance evaluation is not available. For this reason UAM-AERO may be used in a relative sense only. That is to say that the modeling results may be used to inform and supplement a method of speciated linear rollback, rather than use the model results in a traditional modeled attainment test.

1.2 Objectives

The state of Utah is required to develop a plan to demonstrate that it is able to maintain ambient air quality conditions for PM_{10} below the federal 24-hour standard for specific years in the future for the nonattainment area. To aid in meeting the goals of this study DAQ will seek contract support for 1) the development of the emissions inventory, 2) highly resolved prognostic meteorological fields, and 3) consulting for modeling analysis of both input and output data sets. DAQ will provide the modeling expertise for the general development and running of UAM-AERO through a multi-phased effort to apply an aerosol grid model to the Wasatch Front area.

To provide oversight, a Technical Review Panel (TRP) will be formed and retained throughout the effort. This TRP will be made up of representatives of a wide variety of entities that could be affected by, or would have a specific interest in, the application of UAM-AERO results; e.g., EPA, local government agencies, transportation, industry, environmental groups, MPOs, etc. Throughout this process briefings to the TRP are to be made by a combination of letter mailings, routine reports, and meetings at the DAQ office. These meetings will provide a forum for the DAQ modeling team to personally brief members of the DAQ staff and TRP members.

This protocol documents the activities associated with conducting the PM_{10} modeling and evaluating the model's performance prior to its use in emissions control strategy testing. A subsequent addendum to this protocol will be prepared, if needed, to provide more specific information on the methodologies for estimating control strategy requirements, procedures for attainment demonstration, and associated documentation and submittal requirements.

1.3 Choice of Models

It is recommended that the UAM-AERO employing CB-IV chemistry be used as the aerosol model in the PM_{10} SIP modeling. UAM-AERO is an extension of the widely used photochemical model, the Urban Airshed Model (UAM), Version IV, which has been adapted to treat aerosol processes. DAQ chose to use this model because of extensive staff experience using UAM-IV for ozone analysis and because the chemical mechanism in UAM-AERO has been tested more extensively than for other models (Seigneur and Pai, 1999). The key feature of the UAM-AERO model is that it provides a common framework in which to evaluate relationships between ambient concentrations of both ozone and particulate matter (PM), and their precursor emissions. (Kumar and Lurmann, 1996; Lurmann, et al, 1997) Assistance with setup and evaluation of UAM-AERO will be obtained from an experienced contractor.

Given the complexity of the local mountainous terrain, in close proximity to two large bodies of water (Utah Lake and Great Salt Lake), DAQ recommends the use of a high-resolution prognostic meteorological model to develop the meteorological inputs to the UAM-AERO. Specifically, scientists at the University of Utah Department of Meteorology and NOAA Cooperative Institute for Regional Prediction will be responsible for developing meteorological input data for the UAM-AERO. This effort will involve running a prognostic mesoscale model -- the Penn State/NCAR mesoscale model (MM5).

Processing of the emissions data sets assembled for point, area, and mobile sources will be accomplished through use of the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system. This emissions

handling system was developed by EPA for integration into the Models-3 Air Quality Modeling System. SMOKE outputs will need to be modified for input into UAM-AERO. Because winter time episodes will be modeled, estimates of biogenic emissions will not be included in the analysis. The emissions data sets will be created and evaluated by an experienced contractor in consultation with DAQ.

1.4 Overview of the Modeling Project

Since the early 1990's there have not been any major inversion episodes (stagnant conditions persisting for one to three weeks) in the Wasatch Front urban area. It is during stagnant conditions that PM_{10} builds up in the area and as the condition persists, more and more PM_{10} (especially secondary PM) accumulates causing ambient values to exceed the NAAQS. One 5-day episode has been selected during February, 1996 as this episode has the highest ambient PM_{10} values during the past five years. Although the meteorological database from 1996 is more limited than is currently available, there is a chemically speciated data set for some of the PM_{10} monitors on several of the episode days. In June, 1996 a wider network of meteorological observations became available, however, there have not been any candidate episodes to model since that time. DAQ prepared for intensive PM_{10} data collection during the winter of 1999-2000 in hopes of capturing a significant PM_{10} episode, but no high PM_{10} episodes occurred. Appendix A details the protocol for this data collection effort. Since a significant PM_{10} episode did not occur during the winter of 1999-2000, DAQ will analyze another February, 1996 episode for possible UAM-AERO modeling.

For the reasons listed below, DAQ is uncertain about its capability to model the PM_{10} phenomenon with a level of accuracy that one would like for using model results as the basis of regulatory policy.

- There is very limited experience among the modeling community, nation-wide, with aerosol modeling.

- UAM-AERO has been used in a regulatory setting only twice in California, in southern California and the San Joaquin Valley, and both times the use of the model results was rejected as a tool for regulatory policy and SIP development.

- Large uncertainties exist in two primary components of model input; specific areas of the emissions inventory and certain meteorological parameters.

It is with these uncertainties in mind that DAQ proceeds with this study and will determine the performance based on the evaluation discussed in Section 6. If the performance evaluation indicates that UAM-AERO results are not appropriate for regulatory decision-making, then DAQ will apply speciated roll-back methods to proceed with SIP development. UAM-AERO results may be able to elucidate important PM_{10} source sectors which may assist in the speciated roll-back evaluation.

1.5 Schedule

The current schedule for the PM_{10} SIP modeling development is as follows:

Activity	Date
• Submit Modeling Protocol to EPA	November 1, 1999
• Base Year Emissions Inventory Complete	May 15, 2000
• Meteorological Inputs Complete	May 31, 2000
• Future Year Emissions (Growth + Mandatory Controls) Complete	July 14, 2000
• Future Year Emissions for Control Strategies Complete	March 2, 2001
• Base Case Model Runs and Model Validation Complete	March 15, 2001
• Model Future Year (Growth + Mandatory Controls)	April 17, 2001
• Model Future Year including Control Strategies	September 14, 2001
• Submit Final Modeling Summary Report to EPA	September 30, 2001

1.6 Protocol Structure

The structure of this protocol follows EPA's "Guidelines for Regulatory Application of the Urban Airshed Model" (EPA, 1991). Section 2 summarizes current knowledge of the air quality and meteorology of the Wasatch Front area as it influences PM_{10} episodes. Section 2 also identifies the recommended modeling episodes and the modeling domain. The methodology for developing emissions estimates for use in aerosol modeling is described in Section 3; similarly, Section 4 discusses the methodology for developing the meteorological inputs to the model. Section 5 discusses the methodology for developing inputs to the aerosol model as well as details of the aerosol model itself. While every attempt has been made to thoroughly describe the recommended methodologies, there are obviously some details and decisions that cannot be prescribed at this time. Important modeling issues that arise throughout the input preparation process will, of course, be discussed with EPA representatives as appropriate.

Section 6 lays out the procedure recommended for evaluating the performance of the aerosol model. The evaluation methodology is problematic due to the absence of other aerosol modeling studies to form a basis of comparison. Evaluation criteria will be negotiated with EPA Region VIII and will reflect the best understanding available for evaluating model performance. Also discussed in section 6 are some of the diagnostic analyses (e.g., model sensitivity simulations) to be carried out with the emissions, meteorological, and air quality models in order to develop a reliable system of models and data bases. The exact scope of these diagnostic analyses will be determined once experience is gained with the modeling data bases and the specific models, as applied to the Wasatch Front area.

Once the modeling system has been evaluated and judged ready for control strategy evaluation, it will be used to explore future-year emissions reduction scenarios. A discussion is included of the general procedures that have been used in the past for adjusting base-year emissions and other model inputs to reflect desired future-year conditions. These are outlined in Section 7.

2.0 CHARACTERISTICS AND CONCEPTUAL DESCRIPTION OF PM_{10} EPISODES IN THE WASATCH FRONT REGION

High concentrations of PM_{10} in the Wasatch Front Region can be attributed to a combination of meteorological conditions and emissions patterns. A typical pattern which produces high PM_{10} concentrations can be described by the following conceptual description (EPA, 1999). A high pressure system in the Wasatch Front region develops, producing a temperature inversion below the peaks of the surrounding mountains. During the winter, with enhanced surface albedo from snow covered ground and a low sun angle, the inversion is more likely to persist. These inversions are typically most shallow at night and will deepen during the day, dependent on solar heating. In the morning, motor vehicle emissions increase due to the morning rush hour and, since the inversion is shallow, PM_{10} concentrations rapidly increase. As the day progresses, the inversion layer will deepen, allowing PM_{10} concentrations to decrease. If it is a sunny day, the inversion will deepen dramatically, and pollutant emissions may be ventilated out of the inversion layer. If it is cloudy or foggy, the inversion layer will persist, allowing high PM_{10} concentrations to build throughout the day, particularly secondary PM_{10} concentrations. Formation of secondary particulates is enhanced by high relative humidity. Therefore, in the presence of fog, the pollutants are trapped and conditions are conducive to secondary particulate formation. In the late afternoon, the evening rush hour emissions, in combination with the evening decrease in the depth of the inversion layer, will again cause PM_{10} concentrations to increase. This daily pattern is demonstrated in Figure 2-1. Figure 2-2 demonstrates the correlation between shallow inversion layers (low mixing height) and high particulate concentrations. Figure 2-2 also illustrates that PM_{10} consists primarily of secondary particulates (i.e., $PM_{2.5}$) in the Wasatch Front region. Consistent with the above description, the highest PM_{10} concentrations occur in stagnant conditions with low winds (Figure 2-3). This indicates that the particulate problem in the Wasatch Front region is not primarily due to wind blown dust.

2.1 Air Quality

Wintertime primary PM_{10} particulates are generally created during a burning process and include fly ash (from power plants), carbon black (from automobiles and diesel engines), and soot (from fireplaces and wood stoves). The PM_{10} particulates from these sources contain a large percentage of elemental and organic carbon which play a major role in haze phenomena and health effects. Secondary formation processes are also an importatnt contributor toPM_{10} particulate mass in areas having inventories of the chemical precursors.

Elevated PM_{10} levels are generally associated with high density urban areas or localized mountain valleys where industry, automobiles, woodburning, sanding and unpaved roads are common sources. Currently, Salt Lake and Utah counties and Ogden City are designated non-attainment for PM_{10}.

2.2 Meteorology

Most exceedances of the 24-hour average National Ambient Air Quality Standard (NAAQS) for PM_{10} measured along the Wasatch Front occur during extended periods of stagnation during the winter months. The key components of the meteorological conditions during such stagnation periods consist of: an intrusion of a cold air mass; snow cover; light and variable surface winds; surface based temperature inversion; fog or high humidity. Details of the preceding meteorological components of an exceedance episode of the PM_{10} standard are discussed in Section 2.3.

2.2.1 Air Mass Surface Temperature

A PM_{10} episode is normally associated with a cold frontal passage with an associated high pressure system behind the front (surface pressures will build to near 30.40 inches, mercury).

2.2.2 Snow Cover

Snow cover is an element of the meteorological conditions that plays a dual role in the PM_{10} episodes. First, snow cover acts as a reflector of incoming solar radiation which inhibits heating near the surface, thus supporting the formation and maintenance of a surface inversion. Second, the snow cover acts as a source of moisture which helps produce the fog associated with the inversions. The existence of fog plays a role in the chemical reactions which produce secondary sulfate and nitrate.

2.2.3 Winds

The winds during a typical PM_{10} episode are usually light and variable (speeds less that 5 miles per hour), and are influenced by local topographic features. The mountain/valley regime provides diurnal upslope/downslope patterns; the lake/land interface presents onshore/offshore patterns which support and enhance the mountain/valley pattern.

2.2.4 Temperature Inversion

Typically during a PM_{10} episode a surface inversion (increasing temperature with height), which has a top lower than the surrounding mountains, persists for several days. Such inversions create a cap to the pollutants in the lower valley elevations. With respect to the model (UAM-AERO) an important parameter is the diffusion break height (DIFFBREAK) or mixing height (refer to section 5.3.5 for detailed discussion of the DIFFBREAK calculation). The pattern of mixing heights is that the lowest point is in the early morning hours. The top of the inversion during the early morning hours is usually only 100 - 200 feet above the valley floor. Above the inversion the air is clear and clean while areas below the inversion top and at the surface experience high PM_{10} concentrations.

The National Weather Service calculate a daily clearing index which indicates a relative potential for pollutant build-up. The clearing index is a non-dimensional number which combines the height of the inversion (mixing depth) with the wind speed within the mixing depth. When the clearing index is less than 500, dispersion is poor and represents a high potential for high pollutant concentrations. When the clearing index is below 100, severe stagnation conditions exist.

2.3 Candidate Modeling Episodes

Analysis of the meteorological conditions associated with high PM_{10} concentrations in the Wasatch Front region indicate that the highest PM_{10} concentrations occur in conjunction with a persistent inversion and foggy conditions. Because of the lack of persistent inversion periods during the 1990's, there are very few options for PM_{10} modeling episodes. The possible episodes will be discussed in the following sections. In addition to historical episodes, DAQ was prepared to collect data during the winter of

1999/2000 in hopes of capturing a current episode which could be used for this analysis (see Appendix A). There were no occurrences of high PM_{10} during the winter of 1999/2000 so we were not able to obtain information for a more recent episode.

2.3.1 Episode Selection

This section presents the rationale underlying the recommended modeling episodes for the PM_{10} SIP modeling. The recommendations given here represent current thinking regarding the most appropriate episodes for modeling; however, it is seldom possible to appreciate beforehand all of the important modeling and policy implications of a particular episode prior to actually working with the data sets. Therefore, should issues arise subsequently in the process of data base development for any of the episodes that suggest revisiting the episode selection process (e.g., modifying the modeling periods, substituting entirely new episodes), they will be brought to the EPA's attention promptly.

2.3.2 Wasatch Front Episode Selection Methodology

In identifying candidate modeling episodes, the following activities were carried out:

- Define the range of issues that bear on the selection of aerosol modeling episodes (e.g., regulatory planning requirements, model refinement and model performance testing);
- Assess the availability and adequacy of emissions, meteorological, and air quality data for developing model inputs and assessing model performance;
- Identify specific days to be modeled within each candidate episode; and
- Identify the best candidate episodes for use in this study.

General Considerations

In developing the preliminary recommendations on modeling episodes, the available database was examined in terms of the following screening attributes (some were considered explicitly, others implicitly):

PM Maxima – Primary candidates are days for which there are high measured PM_{10} concentrations and also high measured concentrations of other primary and secondary pollutants (i.e., associated pollutants). Specifically, those days with 24-hour PM_{10} values greater than the federal PM_{10} standard (150 $\mu g/m^3$) are considered.

Presence of a Persistent Inversion – Elevated PM_{10} concentrations tend to occur in the Wasatch Front region when there is a persistent strong inversion over the region. Identification of these periods can assist in episode selection.

Data Availability and Completeness – Another criterion used in selecting modeling episodes from the set of available days is data completeness. An acceptable modeling day should have available, at a minimum, complete (or nearly complete) routine monitoring data for preparing model inputs and evaluating model performance.

Specific Considerations

In developing the modeling protocol, each episode was examined in greater detail, with recognition given to the screening analyses identified above. The following were also considered (to the extent supported by readily available information) in developing the final set of candidate days.

Synoptic and Mesoscale Overview – The synoptic and mesoscale meteorological conditions should be representative of those conditions that produce PM episodes.

PM_{10} Maxima of Regulatory Significance – The PM_{10} maxima during the episode should be of sufficient magnitude that the episode can serve as a "design day" for evaluating alternative control strategies.

Representativeness of Design Monitor – The peak monitoring site, or sites, should be representative of regional PM levels and not PM levels produced by individual localized sources or unusual micro-scale meteorological processes.

Representativeness of Emissions Conditions – The episode should not occur during anomalous emissions conditions, e.g., holidays or special events.

Coherence of Surface Wind Patterns – The surface winds should produce fairly stationary, consistent, and predictable flow patterns throughout the modeling domain.

Data Availability for Initial and Boundary Conditions – Adequate surface and aloft data should exist to specify PM and precursor pollutant concentrations at the beginning of the episode (initial conditions) and at the inflow boundaries of the modeling domain (boundary conditions).

Data Availability for PM Performance Evaluation – The number and coverage of PM monitors should be such that the temporal and spatial resolution of these data are adequate to support model performance evaluation.

Data Availability for Multi-Species Testing – The number and coverage of non-particulate precursor pollutant species should be such that the temporal and spatial resolution of these data are adequate to support a performance evaluation of modeled precursor and product species.

Data Availability for Meteorological Model Evaluation – The meteorological data base should be rich enough in spatial (both horizontal and vertical) and temporal detail to support performance evaluation of the meteorological model(s).

Data Completeness – The minimum acceptable set of meteorological and air quality parameters needed for use in preparation of model inputs, performance testing, and control strategy evaluation should be available.

Desired Prototypical Behavior – The episode should display the desired source-receptor relationships that are required to allow assessment of alternative emissions control strategies.

Prospects for Successful Modeling – There should be a reasonable chance of success in producing an acceptable model performance evaluation of the episode, i.e., assessing whether the model performs properly for the correct reasons.

Computational and Schedule Considerations – The modeling analysis should be able to be completed in an acceptable period of time and using available computer resources.

2.3.3 Recommended Episodes

The episode finally selected covers the days with highest PM_{10} concentrations in the period of time spanning 1995-1999, February 11-15, 1996 (see Table 2-1, Table 2-2 and Figure 2-4). EPA generally recommends that episodes are chosen from within the most recent three years of complete air quality monitoring. In this case, those three years would cover 1996-1998. There were no PM_{10} NAAQS violations during this time period so the days with the highest PM_{10} levels will be used as a representative episode. The episode days in the chosen episode include non-holiday weekdays along with a Sunday ramp-up day. Because of the lack of available speciated data and meteorological data, only one episode was chosen from 1996. DAQ collected additional particulate and precursor data during the winter of 1999/2000 in the hope of capturing an appropriate additional episode during this time period. Unfortunately, there were no episodes of high particulates during the winter of 1999/2000. Consequently, another 1996 episode (February 6-9, 1996) will be considered for modeling. We will do a preliminary analysis of the wind fields and, in conjunction with available speciated data, determine whether this episode is suitable for modeling. This earlier February 1996 is less than ideal for the following reasons:

- There is no measured exceedance of the PM_{10} standard during this episode.
- There is essentially no speciated data for this episode.
- The meteorological modeling, in a preliminary analysis, produces unrealistically high wind fields and, because of a lack of meteorological measurements, there is no way to improve upon these meteorological fields.

For these reasons the earlier 1996 episode may not be modeled. However, in the following discussion of the episodes, both February 1996 episodes will be presented in case the earlier 1996 episode needs to be modeled.

The selected episode (Episode #2) shows two exceedances of the 24-hour PM_{10} standard (details shown in Table 2-2). The monitor at the North Salt Lake monitoring site had two exceedances on February 14, 15, 1996 (157 $\mu g/m^3$ and 162 $\mu g/m^3$). The monitor at the Air Monitoring Center had one high PM_{10} value, on February 14, 1996, but this is not technically an exceedance because of EPA

rounding conventions. Although there were no widespread occurrences of PM_{10} exceedances, there were high PM_{10} concentrations at a number of monitors on different episode days, at which speciated data were measured. These data can be used to support model evaluation.

It is recommended that the following episode(s) be modeled:

- Episode 1: February 6-9, 1996 (if meteorological and chemical data are acceptable)
- Episode 2: February 11-15, 1996

Because of the low number of exceedance days since 1994, EPA has agreed to allow DAQ to address the PM_{10} SIP with only one or two representative episodes rather than the generally recommended three episodes. DAQ made every effort to replace Episode #1 from 1996 with a more appropriate episode using a 1999/2000 winter season episode, but no such episode occurred.

2.3.4 Meteorological Conditions During 1996 Episode

During the 1996 episode, the maximum surface temperature was below 7EC (45EF). Episode 2 was slightly warmer than Episode 1 by approximately 1EC to 4EC, depending upon the day in the four day episodic sequence. Table 2-3 depicts the temperature maximum and minimum at the Salt Lake City International Airport (SLCIA) for the two episodes. The surface temperatures along with the upper air profiles indicate that there was in fact a cold air mass that penetrated the Wasatch Front area (all soundings during the episodes depicted substantial surface inversions; see Figures 2-5 and 2-6). The upper air profiler was located at the Salt Lake City International Airport (UTM: 418100 E, 4513500 N; 1288 meter elevation). The surface pressures also were similar to those of typical PM_{10} episodes, ranging from 30.10 to 30.30 and from 30.20 to 30.40 for episodes 1 and 2, respectively. Table 2-3 details the surface conditions (temperature and pressure) at the routine radiosonde observation (raob) times.

For the 1996 PM_{10} episodes, there was continuous snow cover. The four day episode beginning February 6 had a high of 14 inches and a low of 8 inches of snow cover (Table 2-4a). The second episode (February 11 - 15) had snow cover ranging from 4 to 5 inches (Table 2-4b).

Figure 2-7 depicts the average wind speeds (average of all wind monitoring stations) for each day of the episodes. Clearly the wind speeds are similar to the typical episodic light wind cases. The general profiles shown in figure 2-7 support the fact that local terrain highly influences the winds. A peak is evident in the early afternoon (approximately 1300 - 1400 MST), indicating the shift to the complementary, upslope and onshore influences. Figure 2-8 shows the wind speed and direction profiles at the Cottonwood monitoring station (located in the eastern valley area) which also show the terrain influences. By mid afternoon, when the speeds increase, the directions also show the up slope and onshore influences (winds veering from the SSE to the NNW). This terrain influence is slightly more pronounced in the second episode.

2.4 Definition of Modeling Domain

The proposed modeling grid domain is shown in Figure 2-9. This domain was chosen to include the area within which winds might transport pollutants during the 1996 episodes. Wind trajectories for the 1996 episodes demonstrate the adequacy of the chosen domain for these episodes (Figure 2-10). This domain covers all or part of 13 counties and extends from the west edge of the Great Salt Lake to just east of the eastern edge of Utah County, and from Logan in the north to Manti in the south. This grid consists of a 67 x 113 array of 2 km grid cells. Table 2-5 gives the specific grid with its spatial resolution and UTM origins. There is a possibility that the domain size will be reduced dependent upon results of the meteorological modeling. Any alterations in the domain will be finalized by April 15, 2000.

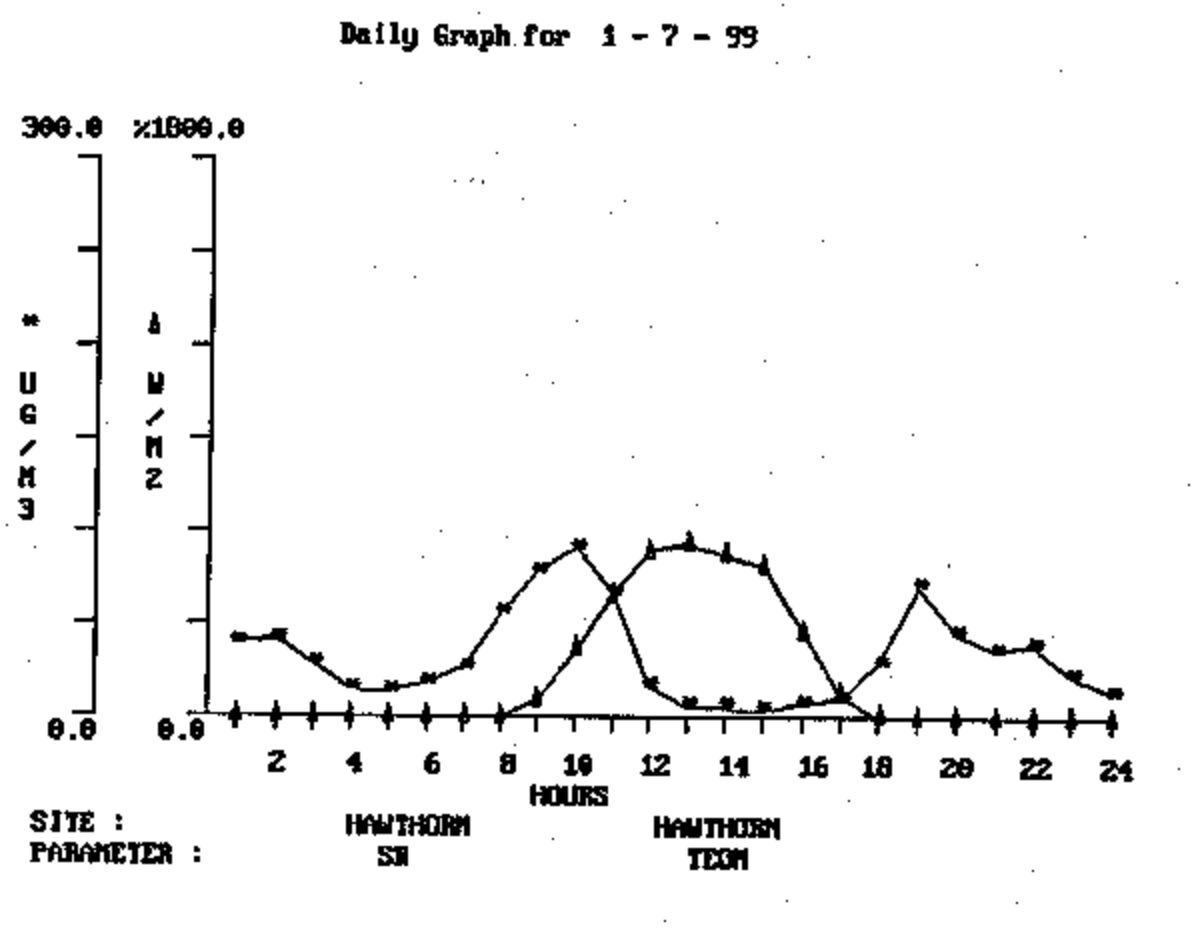


Figure 2-1. Daily Variability in PM_{10} (TEOM) Concentrations and Solar Radiation

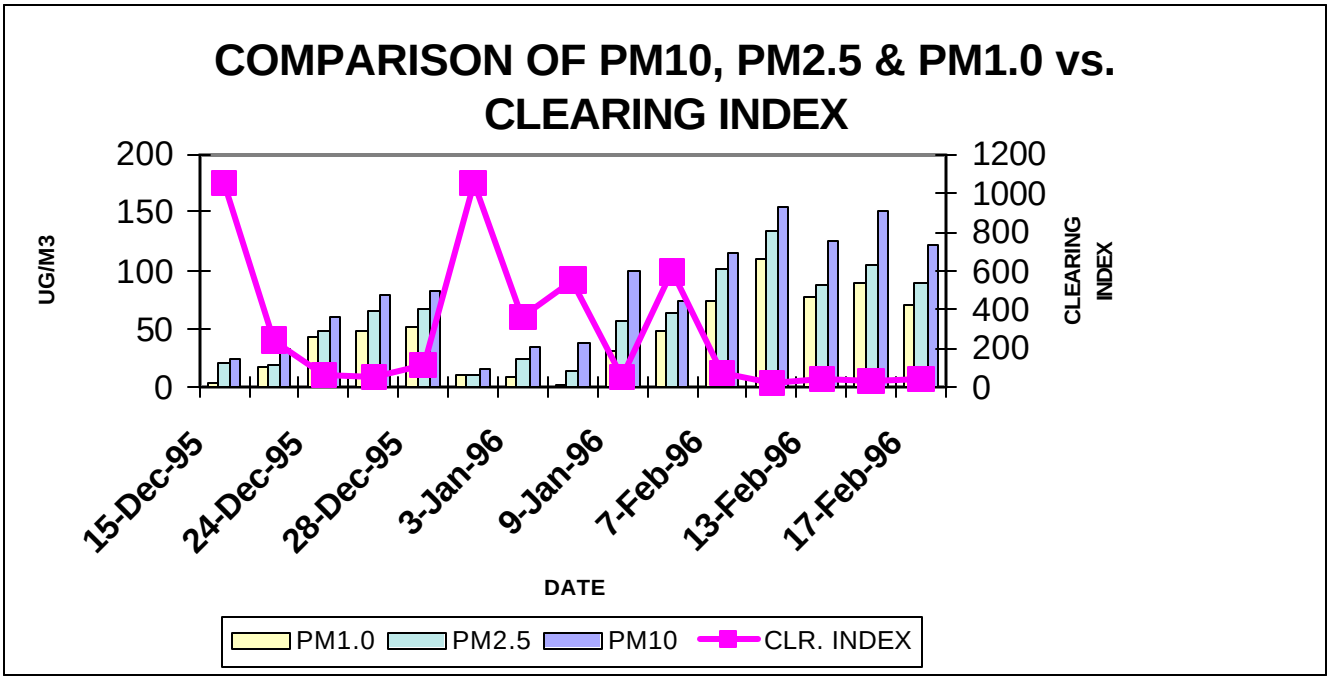


Figure 2-2. Comparison of Particulate Concentrations and Clearing Index
Clearing index is directly proportional to the mixing height. This figure illustrates that a small clearing index (low mixing height and shallow inversion layer) corresponds with high PM concentrations. Notice that the fraction of PM_{10} which is smaller than 2.5 µm represents about 70% of the total PM_{10}. $PM_{2.5}$ generally represents secondary particulates, i.e., sulfates and nitrates.

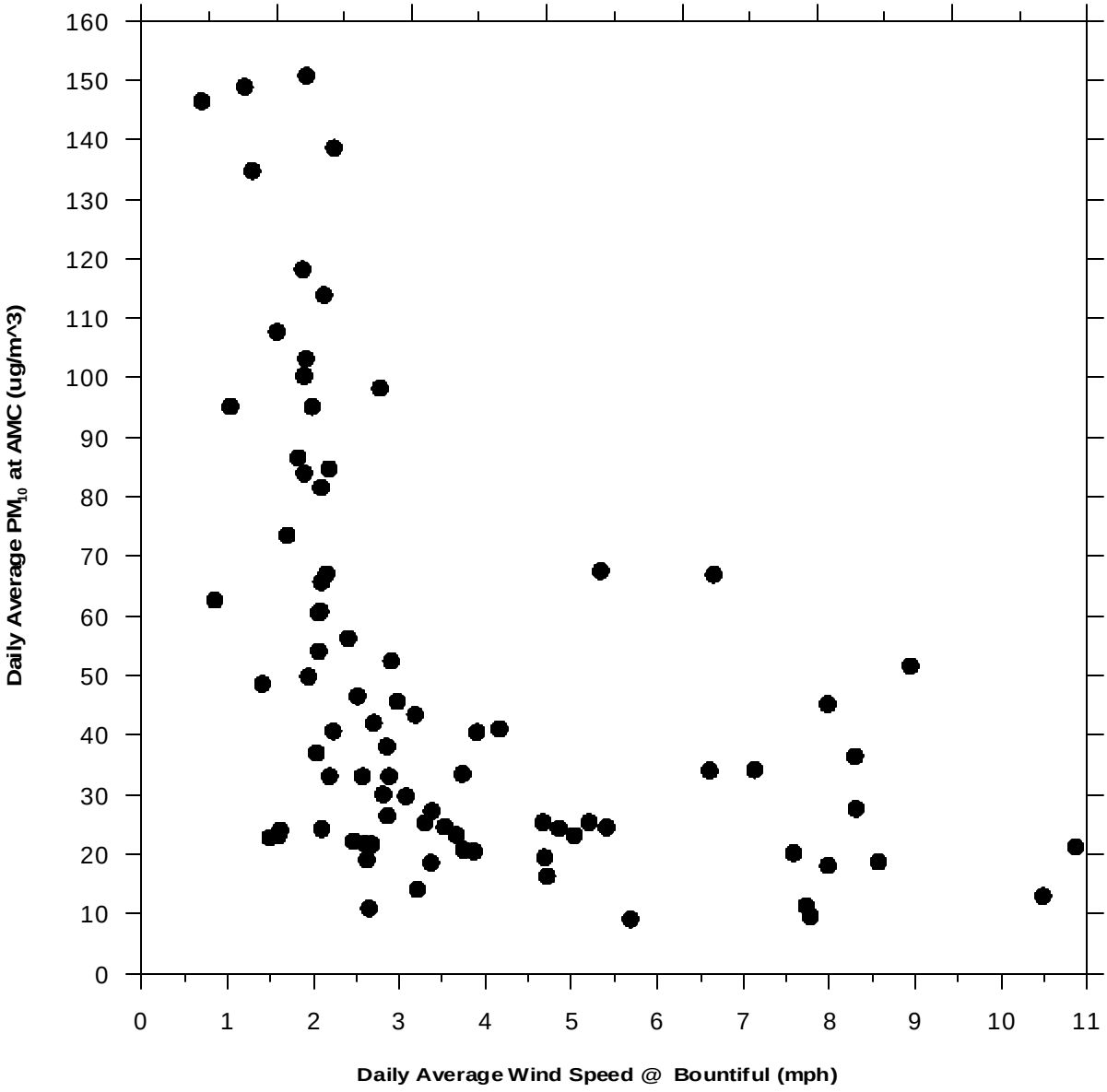
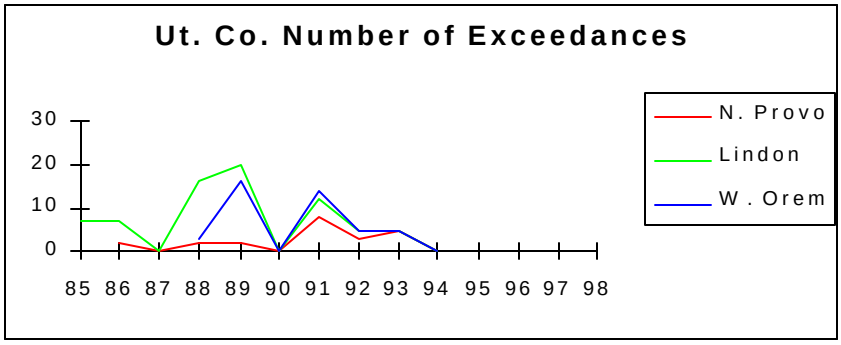


Figure 2-3. Scatter Plot of Daily Average Wind Speed vs. Daily Average PM_{10} (1-3/96)

Utah County PM_{10} Exceedances

Number of Exceedances (>150 ug/m3)

	90	91	92	93	94	95	96	97	98
N. Provo	0	8	3	5	0	0	0	0	0
Lindon	0	12	5	5	0	0	0	0	0
W. Orem	0	14	5	5	0	0	0	0	



Salt Lake County PM_{10} Exceedances

Number of Exceedances (>150 ug/m3)

	90	91	92	93	94	95	96	97	98
AMC	0	14	8	0	1	0	0	0	0
N. SL	0	14	3	1	0	0	2	0	0
SLC	0	5	3	0	0	0			

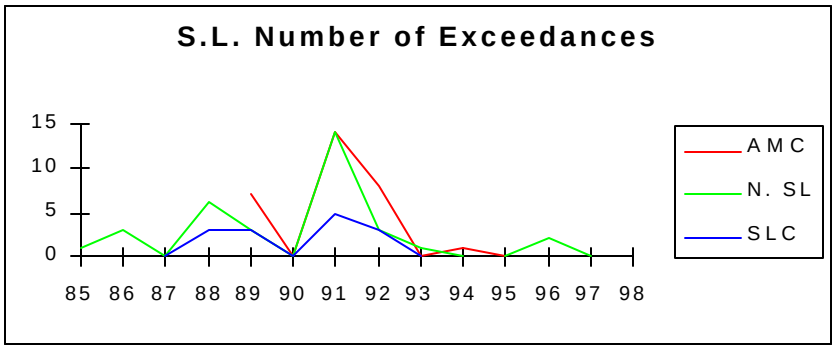


Figure 2-4. Number of PM_{10} Exceedances 1985-1998

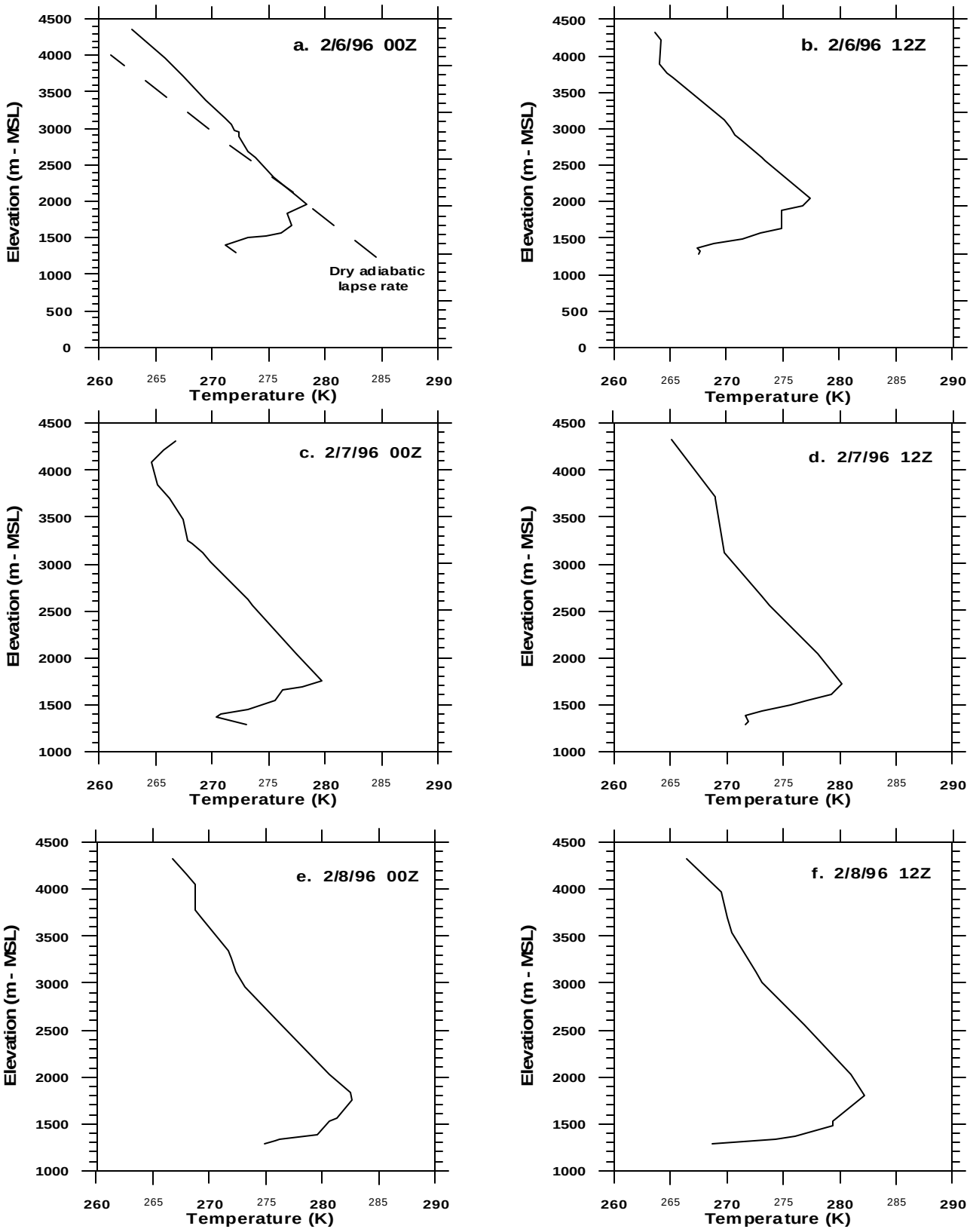


Figure 2-5. PM_{10} February 1996 Episode # 1 raobs

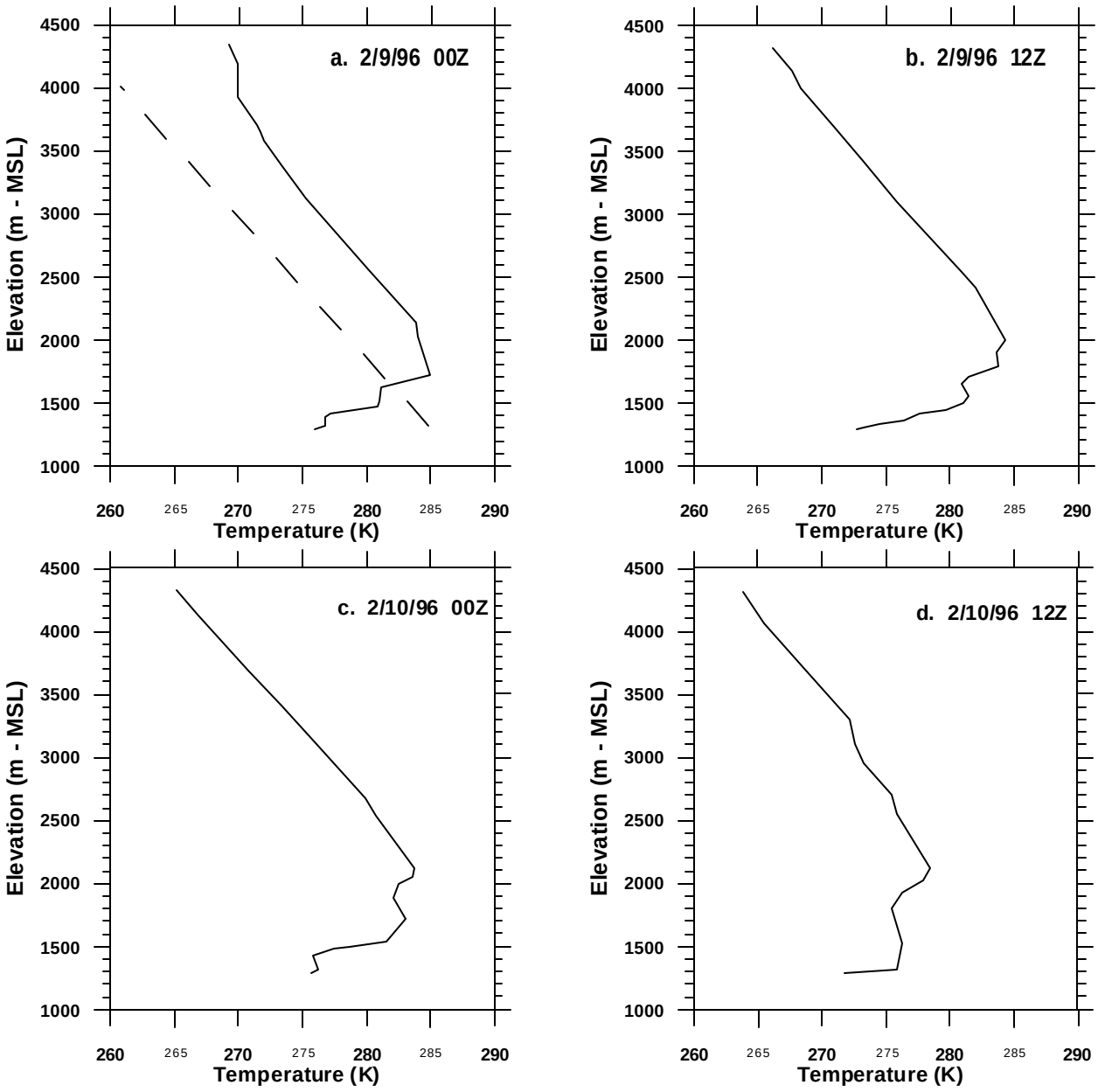


Figure 2-5 (cont.). PM_{10} February 1996 Episode # 1 raobs

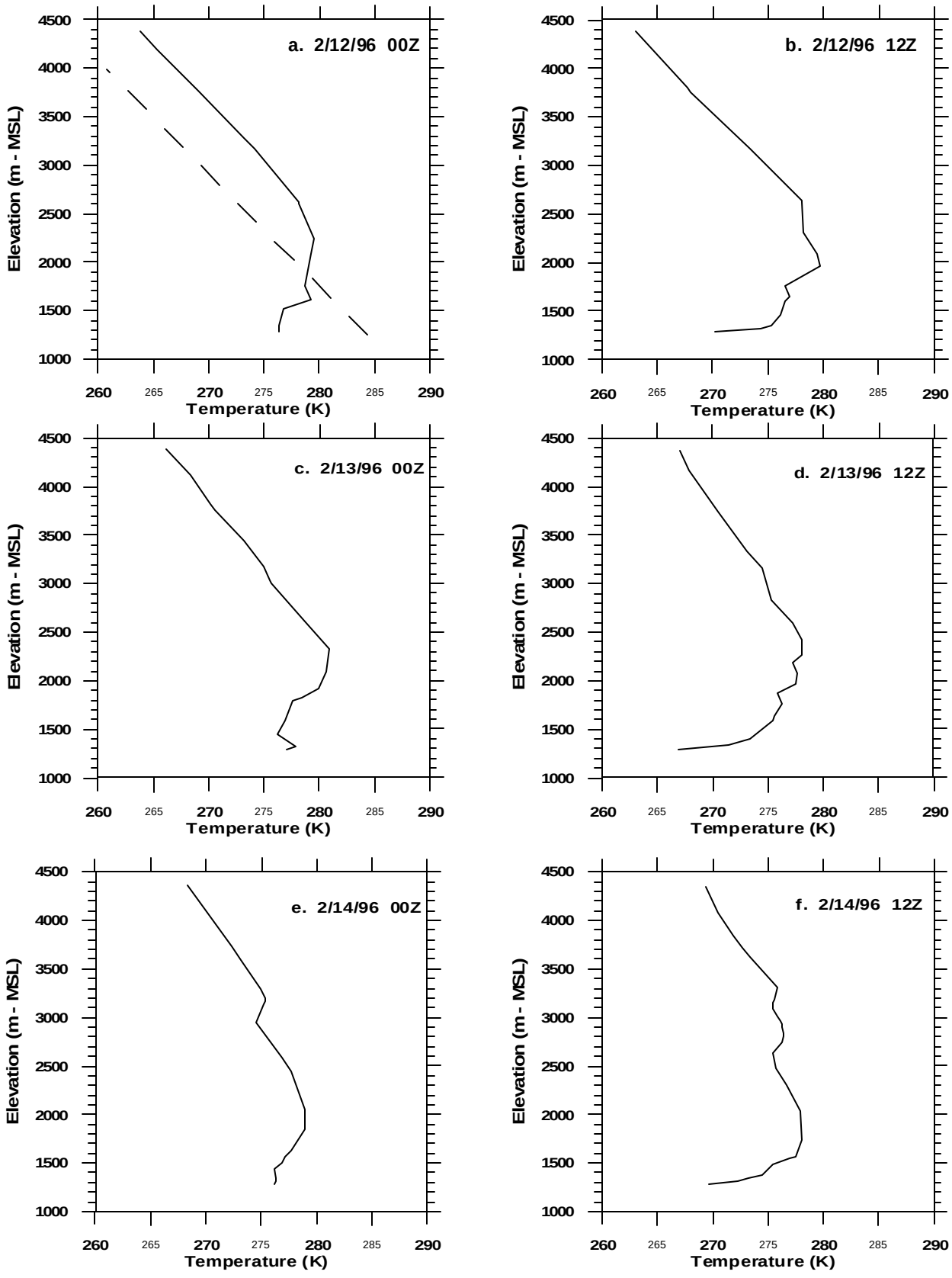


Figure 2-6. PM_{10} February 1996 Episode # 2 raobs

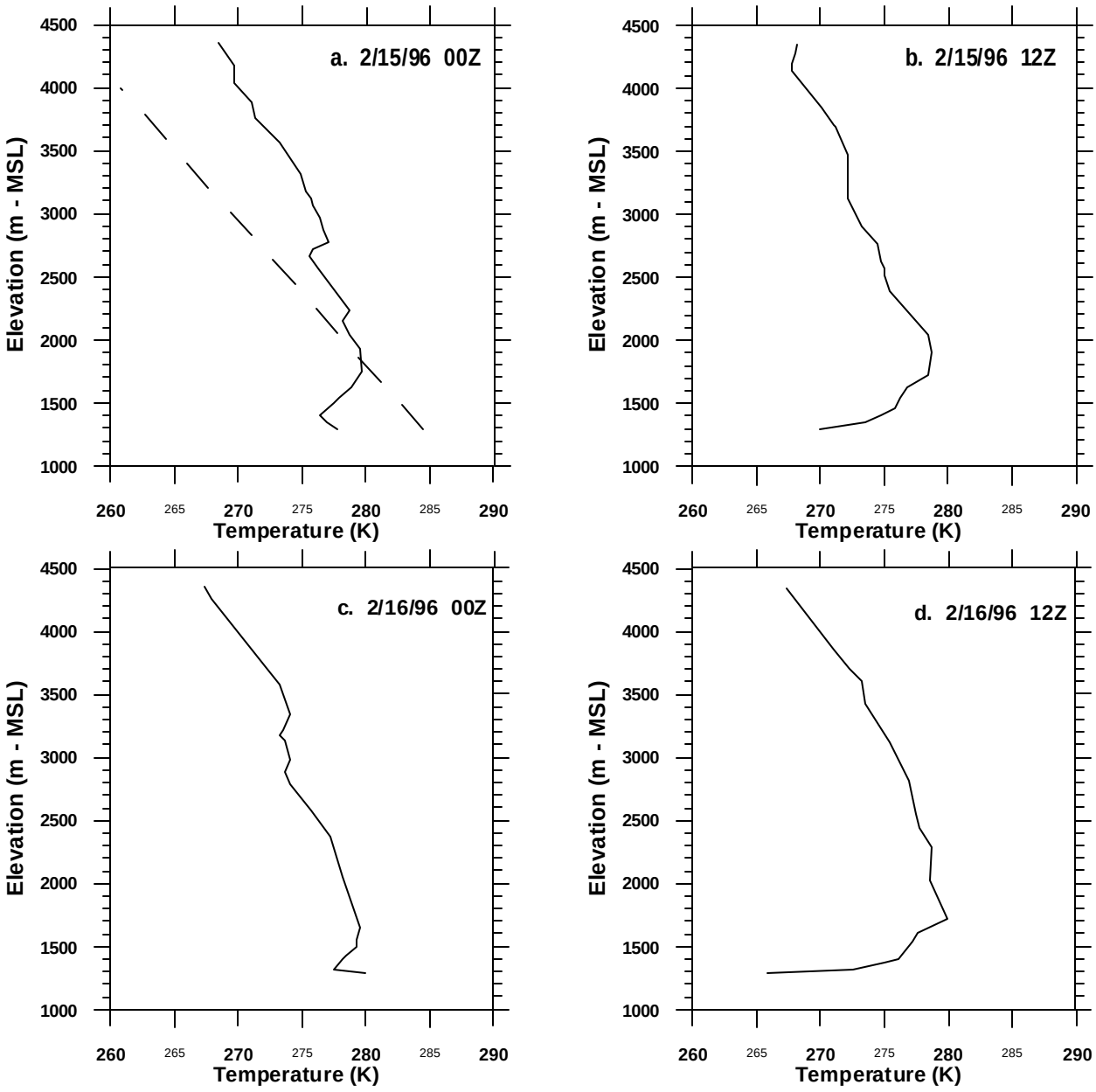


Figure 2-6 (cont.) **PM_{10} February 1996 Episode # 2 raobs**

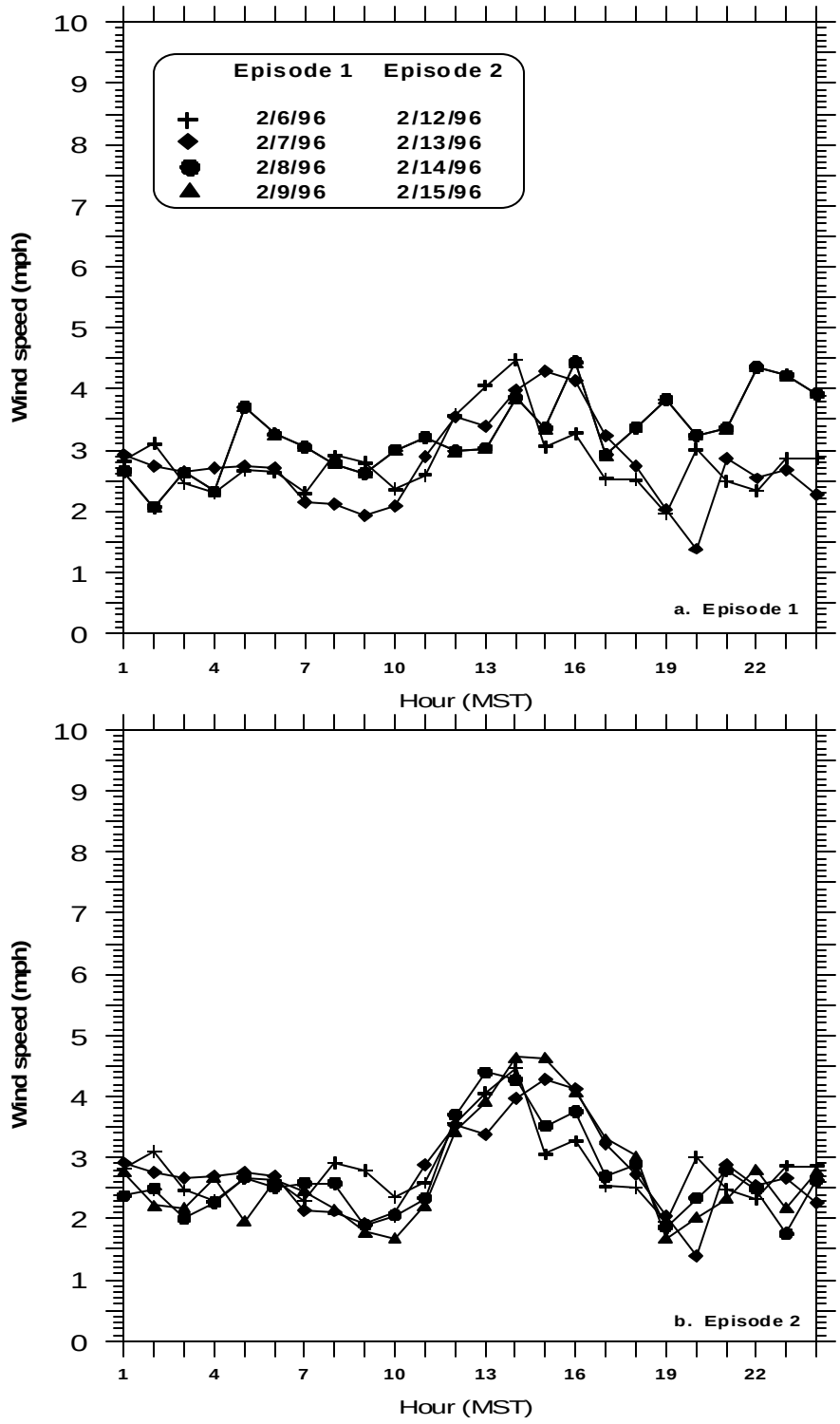


Figure 2-7. Average Wind Speed Profiles for February 1996 Episodes (11 sites)

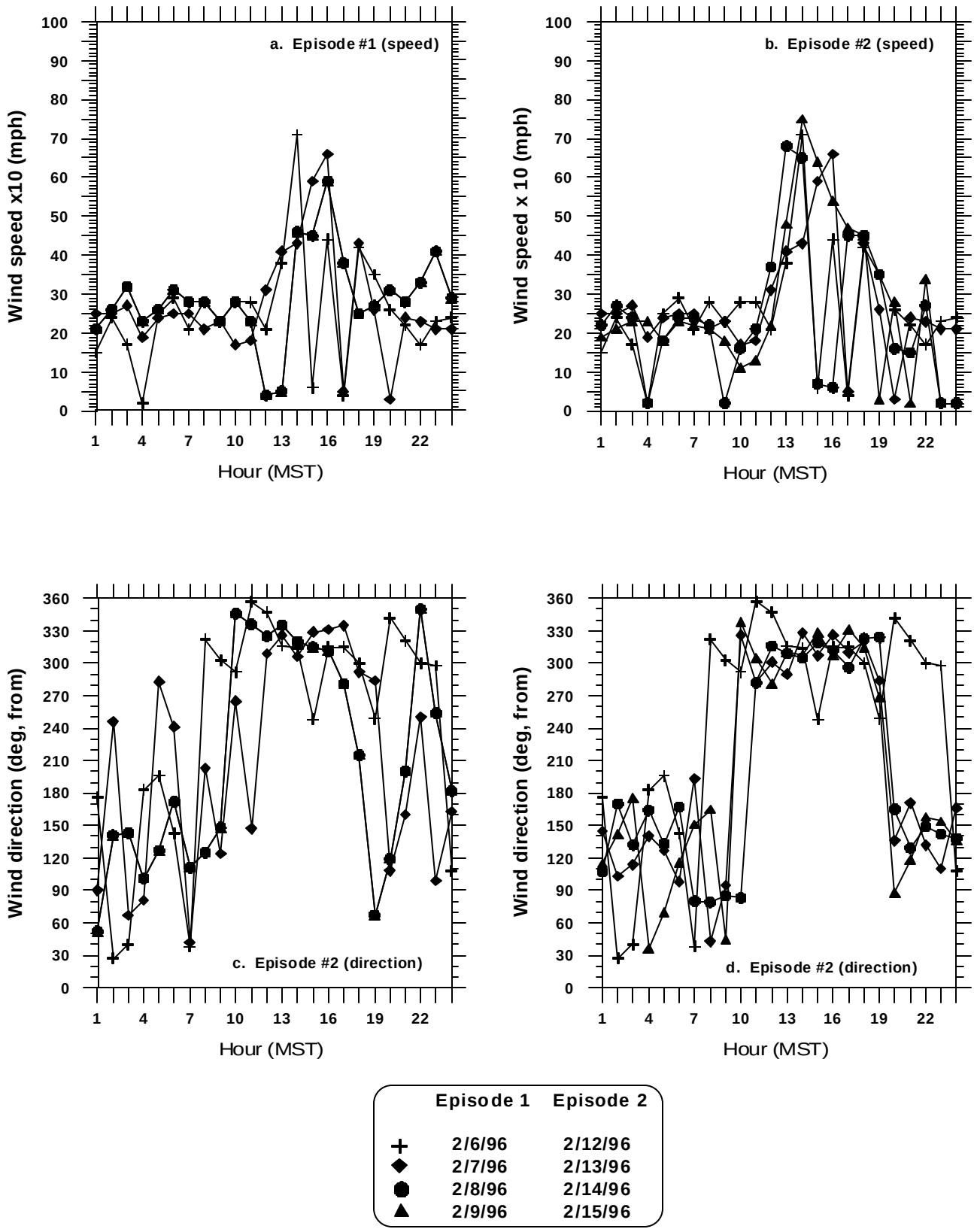


Figure 2-8. Wind Direction and Speed Profiles for Cottonwood for two 1996 Episodes

Table 2-1. Candidate PM_{10} Modeling Episodes for the PM_{10} SIP modeling

Episode	Day of Week	Maximum PM_{10} ($\mu g/m^3$)
6 February 1996	Tuesday	106 (AMC)
7 February 1996	Wednesday	128 (W Orem)
8 February 1996	Thursday	123 (W Orem)
9 February 1996	Friday	154 (AMC)
11 February 1996	Sunday	
12 February 1996	Monday	125 (Lindon)
13 February 1996	Tuesday	143 (NSL)
14 February 1996	Wednesday	157 (NSL)
15 February 1996	Thursday	162 (NSL)

Table 2-2. Summary of February 1996 PM_{10} Measurements

			AMC	Lindon	Magna	N Provo	NSL	Ogden	W Orem	Beach	Bountiful	Cottnwd	Wash Terr
Tuesday	2/06/96		106	81	44		81	72	56				
Wednesday	2/07/96		* 115	113	59	71	112	98	128	67	109	97	61
Thursday	2/08/96		84	109	66	76	86		123				
Friday	2/09/96		* 154	120	82	85	148	79	98	83	126	114	^ 72
Saturday	2/10/96												
Sunday	2/11/96												
Monday	2/12/96		98	125	43	95	99	55	100				
Tuesday	2/13/96		* 125	141	68	101	143	72	114	66	81	107	60
Wednesday	2/14/96		^ 151	^ 147	^ 88	^ 120	^ 157	^ 98	^ 109				
Thursday	2/15/96		* ^ 149	129	^ 103	109	^ 162	^ 96	123	^ 93	^ 104	^ 130	^ 80

^ PM10 speciation

*** PM 2.5 speciation**

Table 2-3. Temperature and Pressure During PM_{10} Episodes

Episode #1							
DATE & TIME GMT (Z)		DATE & TIME (MST)		T (K)	T (C)	P (actual, mb)	P (sfc, IN)
2/6/1996	0000	2/5/1996	1700	272.1	-1.1	881	30.3
	1200	2/6/1996	0500	267.5	-5.7	880	30.3
2/7/1996	0000	2/6/1996	1700	273.0	-0.2	878	30.2
	1200	2/7/1996	0500	271.6	-1.6	878	30.2
2/8/1996	0000	2/7/1996	1700	274.9	1.7	876	30.2
	1200	2/8/1996	0500	268.7	-4.5	876	30.2
2/9/1996	0000	2/8/1996	1700	275.9	2.7	874	30.1
	1200	2/9/1996	0500	272.7	-0.5	873	30.1
2/10/1996	0000	2/9/1996	1700	275.7	2.5	873	30.1
Episode #2							
DATE & TIME GMT (Z)		DATE & TIME (MST)		T (K)	T (C)	P (actual, mb)	P (sfc, IN)
2/12/1996	0000	2/11/1996	1700	276.4	3.2	882	30.4
	1200	2/12/1996	0500	270.2	-3.0	883	30.4
2/13/1996	0000	2/12/1996	1700	277.1	3.9	882	30.4
	1200	2/13/1996	0500	266.9	-6.3	882	30.4
2/14/1996	0000	2/13/1996	1700	276.2	3.0	879	30.3
	1200	2/14/1996	0500	269.7	-3.5	877	30.2
2/15/1996	0000	2/14/1996	1700	277.7	4.5	877	30.2
	1200	2/15/1996	0500	270.0	-3.2	878	30.2
2/16/1996	0000	2/15/1996	1700	279.9	6.7	878	30.2
	1200	2/16/1996	0500	265.9	-7.3	876	30.2

Table 2-5. Grid Definitions for the PM_{10} SIP modeling

(a) Horizontal Grid Definition

Model Code	Grid Cells East-West	Grid Cells North-South	UTM Origin East-West	UTM Origin North-South	Cell Size (km)
UAM-AERO	67	113	348 km	4388 km	2 km
SMOKE	67	113	348 km	4388 km	2 km

(b) Vertical Grid Definition

Model Code	Vertical Grid
UAM-AERO	5 layers - 2 below and 3 above the Diffusion Break
MM5	45-55 Layers

Table 2-4a. SLCIA Climatological Data for February 1996 Episode # 1

UNL = unlimited ceiling; F = fog; H = haze; GF = ground fog; FH = fog + haze

	Sky cover	Ceiling	Visibility		T (F)					RH	Snow cvr.
	(tenths)	(feet x 100)	(mi)	Weather	Min	Max	(Average)	(Wet Bulb)	(Dew Point)	(%)	(inches)
Feb 06											
Hour											
2	10	1	0.06	F			20	20	29	100	
5	10	1	0.06	F			23	23	23	100	
8	10	1	0.06	F			22	22	22	100	
11	10	2	0.75	F			30	30	30	100	
14	10	2	0.50	F			33	30	30	89	
17	10	1	0.06	F			30	30	30	100	
20	10	1	0.50	F			30	30	30	100	
23	10	70	2.00	F			29	29	28	100	
					13	39					14
Feb 07											
Hour											
2	10	80	1.00	F			26	26	25	96	
5	10	60	2.00	F			29	29	29	100	
8	10	50	3.00	F			33	32	31	92	
11	10	70	2.00	H			35	33	31	85	
14	10	UNL	7.00				44	39	32	63	
17	8	UNL	4.00	H			38	35	32	79	
20	4	UNL	3.00	F			24	33	32	92	
23	3	UNL	4.00	F			31	31	30	96	
					22	46					13
Feb 08											
Hour											
2	9	200	1.00	GF			22	22	21	96	
5	5	UNL	0.25	GF			19	19	18	96	
8	10	UNL	10.00				32	31	29	89	
11	10	UNL	10.00				44	39	32	63	
14	10	UNL	6.00	H			42	38	33	71	
17	10	200	5.00	H			38	36	33	82	
20	10	200	3.00	F			33	33	32	96	
23	10	200	3.00	F			33	33	32	96	
					16	49					12
Feb 09											
Hour											
2	10	200	2.00	F			30	30	30	100	
5	10	200	2.00	F			30	30	29	96	
8	10	200	3.00	F			29	29	28	96	
11	10	UNL	2.00	FH			40	37	32	73	
14	10	200	1.50	FH			40	37	33	76	
17	10	200	2.50	FH			38	36	33	82	
20	10	200	3.00	FH			36	35	33	89	
23	10	200	3.00	FH			36	34	31	82	
					23	42					8

Table 2-4b. SLCIA Climatological Data for February 1996 Episode # 2

UNL = unlimited ceiling; F = fog; H = haze; GF = ground fog; FH = fog + haze

	Sky cover	Ceiling	Visibility		T (F)					RH	Snow cvr.
	(tenths)	(feet x 100)	(mi)	Weather	Min	Max	(Average)	(Wet Bulb)	(Dew Point)	(%)	(inches)
Feb 12											
Hour											
2	3	UNL	6.00	F			28	28	27	96	
5	6	UNL	5.00	F			20	20	19	96	
8	1	UNL	4.00	F			24	24	23	96	
11	1	UNL	5.00	H			44	36	26	49	
14	0	UNL	3.00	H			42	37	31	65	
17	0	UNL	6.00	H			38	34	28	67	
20	0	UNL	10.00				32	30	28	85	
23	0	UNL	5.00	F			31	30	29	92	
					17	45					5
Feb 13											
Hour											
2	0	UNL	5.00	F			27	27	26	96	
5	1	UNL	4.00	F			22	22	22	100	
8	0	UNL	3.00	FH			25	25	25	100	
11	2	UNL	3.00	H			36	33	29	76	
14	6	UNL	3.00	H			40	36	31	70	
17	3	UNL	5.00	H			39	35	30	70	
20	1	UNL	4.00	H			34	33	31	89	
23	0	UNL	4.00	H			30	28	25	82	
					17	45					4
Feb 14											
Hour											
2	2	UNL	3.00	FH			28	28	28	100	
5	1	UNL	5.00	FH			27	27	26	96	
8	0	UNL	1.50	FH			21	21	20	96	
11	0	UNL	2.00	H			40	36	30	68	
14	2	UNL	2.00	H			39	35	39	37	
17	1	UNL	3.00	H			42	38	31	71	
20	0	UNL	4.00	H			36	34	32	85	
23	0	UNL	3.00	H			31	30	28	89	
					15	44					4
Feb 15											
Hour											
2	3	UNL	2.00	FH			25	25	25	100	
5	3	UNL	2.00	FH			25	25	25	100	
8	1	UNL	1.00	FH			26	26	26	100	
11	1	UNL	1.50	FH			44	39	32	63	
14	1	UNL	2.00	H			41	37	32	70	
17	0	UNL	3.00	H			43	39	33	68	
20	0	UNL	3.00	H			37	35	33	86	
23	0	UNL	3.00	FH			34	33	32	92	
					21	46					4

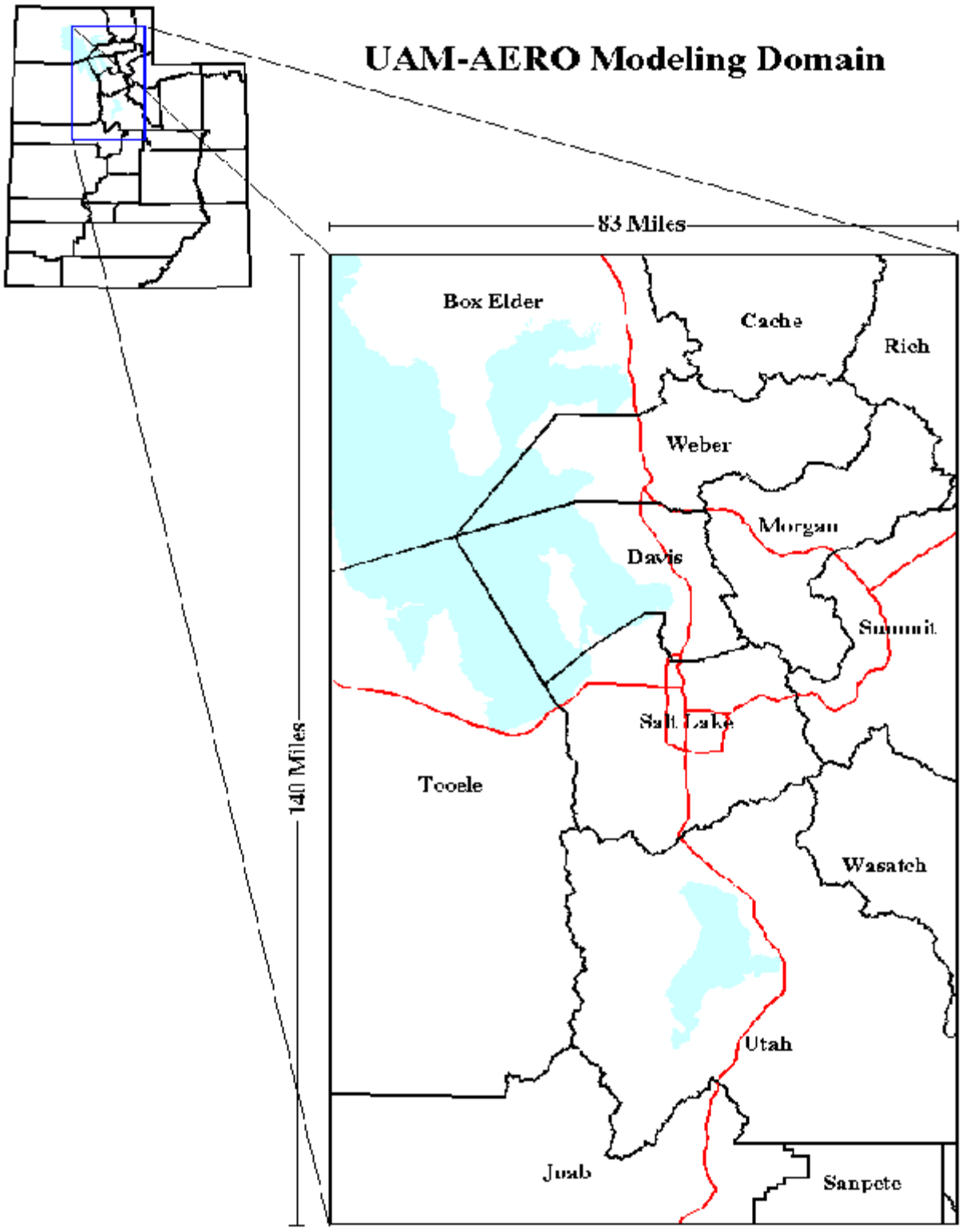


Figure 2-9. UAM-AERO Modeling Domain
67 x 113 array of 2-km grid cells

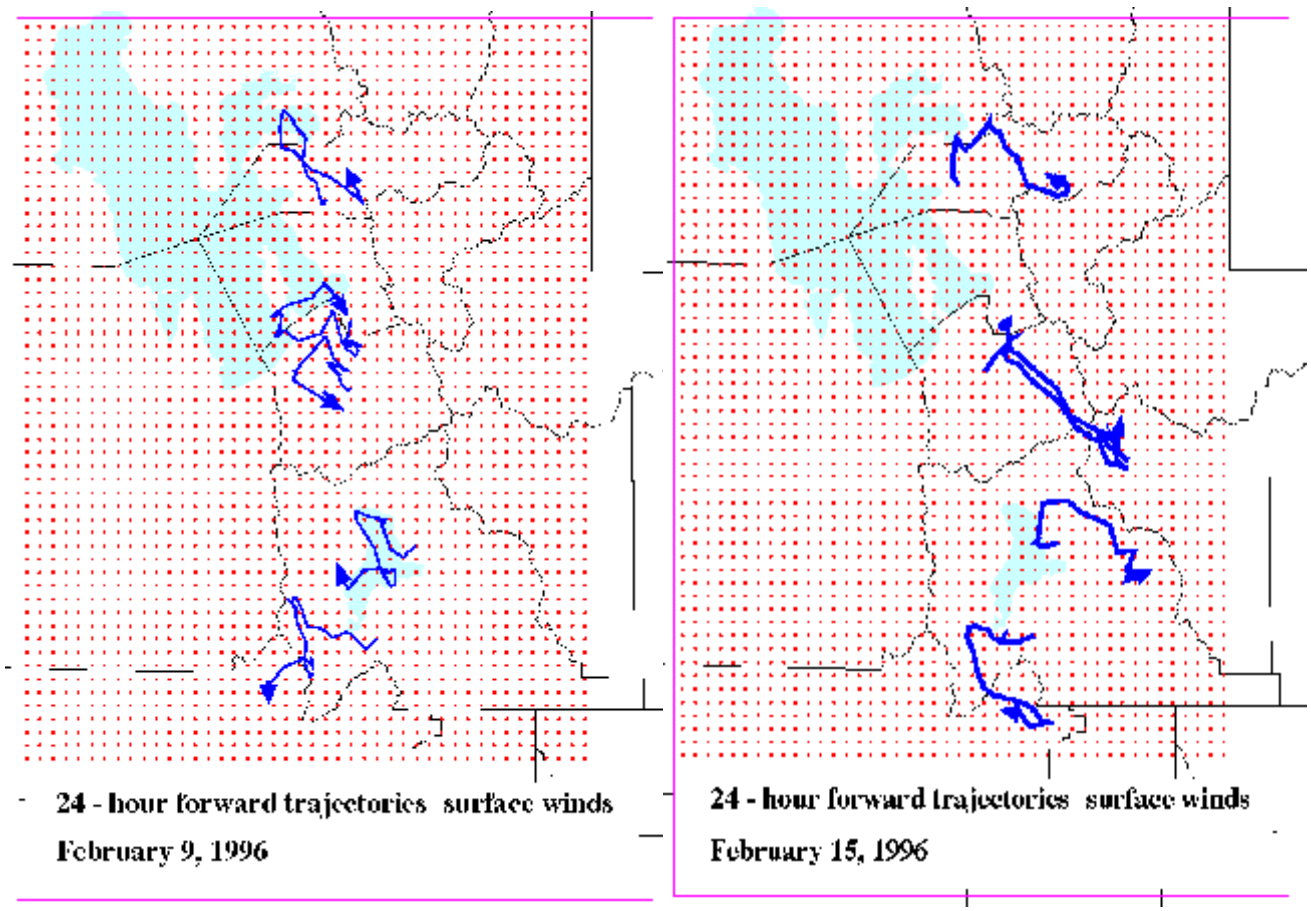


Figure 2-10. 24-hour Forward Trajectories for Surface Winds February 1996 Episodes
The outer boundary represents the UAM-AERO modeling domain; the dots are the grid cells of the 4 km UAM-IV domain which was used for the Wasatch Front Ozone Study.

3.0 EMISSIONS MODELING METHODOLOGY

This section discusses the procedure for generating emissions inputs for the aerosol model.

3.1 Emissions Data Preparation

This section outlines the steps to be followed in developing emissions inputs to the UAM-AERO for each of the modeling episodes.

3.1.1 Delineation of Air Quality Planning Areas

The emissions modeling will cover the UAM-AERO modeling domain. This area includes Salt Lake, Utah and surrounding counties. Although Salt Lake and Utah counties are non-attainment for PM_{10}, there have not been any PM_{10} NAAQS violations since 1995. This modeling effort will focus on Salt Lake and Utah counties because these areas do not meet conformity requirements for PM_{10}.

3.1.2 Emissions Preprocessor System

The U.S. EPA developed the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system as part of the Models-3 Air Quality Modeling System. SMOKE is designed to create emissions inputs for photochemical or aerosol models from the basic point and area source emissions data typically compiled by state or local governmental agencies. SMOKE is a state of the art modeling system which will be used for developing UAM-AERO emissions inputs. The following discussion highlights the general features of SMOKE and presents the specific steps to be followed in exercising SMOKE with the emissions data sets for the study region. Figure 3-1a depicts the SMOKE system flow diagram for base case modeling; Figure 3-1b depicts the SMOKE system flow diagram for control strategy modeling.

3.1.3 Data Bases

Base year 1996 emissions inventories for the study region will be developed from the basic emissions data sets compiled by the U.S. EPA and the Utah Division of Air Quality.

3.1.4 DAQ Emissions Data

The 1996 base year emissions inventory for mobile, area and point sources for the UAM-AERO modeling domain will be compiled. The DAQ 1996 inventory will be reviewed at this stage in a preliminary quality assurance to ensure that complete data files have been captured and that no "suspect" point or area-wide sources are present. This review will help to confirm that the data are complete and representative of typical operating characteristics.

3.1.5 Land Use and Land Cover Data

Land use and land cover data are needed to perform several functions in developing a gridded emission inventory for use in the UAM-AERO. These data will be used to provide spatial allocation of county

wide emissions from area and mobile sources. County-wide emissions estimates will be disaggregated to individual grid cells in the modeling domain by using spatial allocation surrogates. Spatial surrogates will be developed from land use/land cover data and from demographic information. Typical surrogates include urban, suburban, rural, and agricultural land use as well as housing and population distributions. Spatial allocation factors are determined by calculating the fraction of a county's total for each surrogate in each grid cell. This fraction is then used to apportion county total emissions for each source category to individual cells.

Demographic and land use data will be acquired from the Utah Office of Planning and Budget and from the two metropolitan planning organizations (MPO's) for the Wasatch Front modeling region. Land cover data, railroad links and airports will be obtained from the USGS and digitized for allocating emissions from these categories. On-road motor vehicle traffic in the four-county Wasatch Front urbanized area will be allocated using the link location and volume data available from the MPO's MINUTP transportation modeling. Since on-road motor vehicles comprise a large fraction of the regions' emissions, they will receive considerable emphasis in the inventory preparation process. Any modification to the EPA-approved MOBILE5b outputs will be used exclusively for model sensitivity evaluations.

3.2 Compilation of Emissions Estimates

3.2.1 General Emissions Inventory Information

The 1996 DAQ inventories will be assembled to ensure that emissions estimates are available for each grid cell in the full Wasatch Front modeling domain. The processing (e.g., spatial, temporal, and chemical gridding of emissions estimates) will be completed largely by using SMOKE. For example, SMOKE can take SIP inventory data and link-specific traffic volumes and produce gridded, speciated emission output files. SMOKE is designed to allow for adjusting emissions estimates to account for day-specific temperature effects; for time of day, day of week, month, and season, as well as projecting emissions into the future or backward to a historical episode accounting for emissions control effectiveness. Therefore, on-road motor vehicle emissions will be adjusted to account for episodic temperature effects. In addition, an attempt will be made to obtain day-specific activity information to adjust emissions from major point sources in the study domain. SMOKE provides national default parameters for temporally adjusting annual emissions and chemically speciating VOC emissions. Locale-specific data will be used preferentially over the national defaults where possible.

The UAM-AERO requires two emissions input files: (1) low-level sources, and (2) elevated point sources. Low-level emissions consist of low-level point sources, area sources, and mobile sources. The low-level area and mobile source emissions can be provided directly from the output of SMOKE. The SMOKE output file format is structured in three separate files covering point, area, and mobile sources. Additionally, the point sources are further divided into low-level and elevated point sources. Low-level point sources are those which have release points below the plume rise cut-off altitude and are eventually merged into the low-level sources for input to UAM-AERO. The remaining point sources, having discharge elevations greater than the plume rise cut-off point, are treated as elevated point sources. These latter sources are further processed with ELEVPOINT and TMPPOINT to account for episodic meteorological conditions and to inject the emissions into the proper vertical layer of the UAM-AERO.

All low-level emissions are then merged using SMKMERGE to create the low-level emissions input file for UAM-AERO.

3.2.2 Point Source Processing

Typical industrialized urban areas have thousands of point sources. Because it is impractical to treat every point source individually, some aggregation of point sources is necessary. Generally, sources emitting more than some threshold value or sources, regardless of size, exhibiting plume rise of approximately 25 m or more are treated as point sources. Smaller sources are typically aggregated as area sources. The essence of point source emissions processing in SMOKE is converting inventory pollutant data for point source stacks from an aggregated annual, daily, or hourly emissions value to hourly and gridded emissions of the chemical species used by an air quality model.

The plumes arising from point source emissions extend high into the vertical structure of the air quality modeling grid definition. For these sorts of plumes, the plume rise needs to be modeled, and the emissions from these sources provided to the air quality model in three dimensions. An effective plume height for each point source to be treated is calculated based on an adaptation of the Briggs (1975) plume rise equations. These equations require as input stack height, diameter, temperature, and exit velocity as well as wind, ambient temperature, and Pasquill stability class.

The remaining point source processing steps are speciation, temporal allocation, projection, control, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each county, SCC code, plant ID, and stack ID is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles.

3.2.3 Area Source Processing

The procedure for gridding area source emissions estimates is well documented and straightforward. Generally, data are collected either by a state agency or by local air pollution control districts. Typically, the completeness and specificity of these data bases vary considerably from one urban region to another, depending largely upon the level of effort given to quality assurance of the basic information. Based on work recently completed for a planning study in the Wasatch Front area, the available spatial surrogate data (e.g., population, housing, employment, agricultural, water, forest) are reasonably up-to-date, accurate, and complete.

The essence of area source emissions processing in SMOKE is converting inventory pollutant data for counties and source categories from an aggregated annual emissions value to hourly and gridded emissions of the chemical species used by an air quality model. The remaining area source processing steps are speciation, temporal allocation, projection, control, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each county and ASCT code is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles.

3.2.4 Mobile Source Processing

The essence of mobile source emissions processing in SMOKE is converting link and county (a.k.a., non-link) vehicle-miles travelled (VMT) data to hourly gridded emissions of the chemical species used by a air quality model. In order to do this, SMOKE creates, manages, and applies MOBILE5 emissions factors to the VMT based on a user-defined definition of a "mobile control strategy". This control strategy can define the motor-vehicles parameters either for a specific year as it actually occurred, or for a hypothetical control strategy in the past, present, or future.

Emission factors are created in SMOKE using MOBILE5, for a wide variety of exhaust and evaporative processes and pollutants. Some of the MOBILE5 inputs parameters implement control strategies (e.g., inspection and maintenance (I/M) programs, anti-tampering programs (ATPs), and reformulated gas (RFG)). Other MOBILE5 inputs define other factors contributing to the value of the emissions factors, such as vehicle registrations (which help define the mix of different vehicle types), fuel volatility parameters, speeds, and temperature. All of these different dependencies cause mobile SMOKE to be more complicated than other SMOKE component models.

The remaining mobile source processing steps are speciation, temporal allocation, projection of VMT, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each combination of county, road class, and link is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles. Typically, the highway network configuration and estimates of roadway traffic volumes are available with which to construct these link-based estimates. In areas where this information is missing or in short supply, it is possible to develop these inputs from total fuel sales, vehicle registrations, and similar information. Note, however, that a more detailed mobile source emissions modeling approach, utilizing output from the MINUTP transportation demand model, will be used in the urbanized portion of the study domain.

The MPOs and UDOT will be preparing VMT and speed data for the non-attainment counties as well as portions of other counties which fall within the modeling domain. Where feasible, results of transportation modeling of the study area will be used to support the development of on-road mobile source emissions estimates. If this information is not available, then county-level VMT data by vehicle class and roadway type will be used to estimate on-road emissions in the study area. The results of transportation modeling or these coarser VMT estimates will be used in conjunction with motor vehicle emissions factors from EPA's MOBILE5b model to provide the basis for estimating emissions from on-road motor vehicles. The MOBILE5b emissions factor modeling will incorporate locale-specific input parameters including hourly episodic temperatures. Estimates of vehicle miles traveled, vehicle hours of travel, and other relevant parameters will be obtained for the entire modeling region. The transportation modeling will also provide data necessary for spatial and temporal allocation of the on-road motor vehicle emissions data. On-road mobile source emissions for outlying portions of the domain will be spatially allocated using a combination of gridded population and/or land-use data and link locations.

Typically, the highway network configuration and estimates of roadway traffic volumes are available with which to construct these link-based estimates. In areas where this information is missing or in short supply, it is possible to develop these inputs from total fuel sales, vehicle registrations, and similar information.

Emissions factors for each type of on-road vehicle class (e.g., light duty auto, light duty truck, heavy duty truck) and various technology types (e.g., catalyst, non-catalyst, diesel) will be developed from "emissions factor models" such as the MOBILE5b. The emissions factors used in conjunction with the link data mentioned above will address:

- Locale-specific inspection/maintenance (I/M) control programs, if any;
- Adjustments for running losses;
- Splitting of evaporative and exhaust emissions into separate source categories;
- Accounting for vehicle miles traveled (VMT) fleet fractions for light-duty gasoline vehicles and light-duty gasoline trucks;
- VMT growth, fleet turnover, and changes in fuel composition and Reid vapor pressure (RVP); and
- Factors to adjust base-year emissions from annual average to episodic conditions.

3.2.5 Biogenic Sources

Since the PM_{10} episodes occur during winter, biogenic emissions are assumed to be negligible.

3.3 Temporal Adjustments and Speciation Profiles

3.3.1 Temporal Resolution of Emissions

To estimate hourly concentrations of particulates and precursor species, the UAM-AERO requires hour-by-hour estimates of emissions in each grid cell. There are several approaches for providing the temporal detail needed in the modeling inventory. The most accurate and exacting approach is to determine the emissions (or activity levels) for specific sources for each hour of a typical day in the time period being modeled. This approach, while applicable to certain of the major point sources in the Wasatch Front study area, is impractical for all sources.

The alternative approach to be followed involves reviewing available data and developing typical hourly patterns of activity for each source category and then applying these to the annual or seasonally-adjusted emissions to estimate hourly emissions. This approach, consistent with EPA guidelines, is commonly employed for area sources, and is usually used for all but the largest point sources. On-road motor vehicle emissions will be temporally allocated by using hourly traffic volume information, expected to be

available for the major roads in the Wasatch Front study area. For most area and point source emissions categories, the EPA provides default temporal activity profiles. These defaults will be used in this study unless more relevant, site-specific data can be located, which allows more refined temporal allocation estimates.

Emissions are generally estimated for the day of the week on which polluting activities are at a maximum, normally a weekday. In some cases, simulating weekend conditions when automotive and industrial emissions levels are reduced or temporally shifted may be necessary. Here, additional temporal pattern information pertaining to weekend days must be used to construct a weekend modeling inventory.

3.3.2 Chemical Resolution of Emissions

Chemical speciation of emissions for UAM-AERO is described by the "User's Guide to the UAM-AERO Model" (Kumar and Lurmann 1996) and by Lurmann, et. al. 1997. In summary, the NO_x emissions are partitioned into NO, NO_2 and HONO. The NMOC emissions are partitioned into the appropriate classes for the CB-IV chemical mechanism. The PM_{10} emissions are partitioned into six chemical classes and approximately eight size bins below 10 µm and one or more size sections above 10 µm for fog droplets. The six PM_{10} chemical classes include sulfate, elemental carbon, organic carbon, crustal (or other PM species), sodium, and chloride. In addition, in the Wasatch Front region NH_3 emissions are an important consideration and may be identified individually rather than aggregated with the "other species".

3.4 Day-Specific Adjustments

Average winter day emissions will be used for area and low-level point source emissions. Unless episode day-specific activity and emissions data for major sources can be readily obtained, the temporal allocation will be based on the daily profile available for each source in AIRS AFS, and the emissions will be equal to the 1996 base year emissions.

3.5 Quality Assurance

A thorough review and quality assurance of the basic DAQ emissions data sets to be used in this study is well beyond the scope of this protocol. However, in the process of assembling and utilizing the DAQ emissions data sets, there are some activities that will be carried out to help identify the presence of potential problems or inconsistencies in the emissions sets. These activities are discussed below.

3.5.1 Assessment of EPA and DAQ Emissions Data Sets

Reasonable attempts will be made to assure that the 1996 DAQ and EPA Interim 1996 Emissions Inventory data are as complete and correct as possible. "Spot-checks" will be performed on the agency-supplied data sets to see if there are any major errors or consistency problems. During the reformatting process and the initial SMOKE executions, any missing parameters that would cause emissions to be dropped or misallocated will be investigated. Examples of errors that have occurred in similar databases in the past include:

- ASC/SCC codes missing from the SMOKE cross-reference tables, due to invalid or missing ASC/SCC codes; and

- Missing UTM coordinates for point source emissions.

To assure that the emissions are being properly handled by SMOKE, several emissions summary plots and tables will be produced and examined. The total emissions in the original input data sets will be calculated and compared with the emissions processed through SMOKE. The summary reports produced by each module of SMOKE will be examined and reconciled with the reports from other modules. In addition, plots of total daily emissions and selected hourly emissions will be produced for area source emissions, elevated point source emissions, low level (non-elevated) point source emissions, and motor vehicle emissions. These plots will be examined for spatial distribution and compared with area maps to confirm correct distribution.

3.5.2 Review of EPA Defaults and Data Sets

The default cross reference and lookup files provided by EPA for use with SMOKE for the Wasatch Front study area will be cross referenced. In particular, the following files will be reviewed and updated for conditions specific to the Wasatch Front area:

- Spatial surrogate files;

- Speciation profile files; and

- Temporal allocation files.

3.5.3 Preparation of Emissions Summary Reports and Plots

To aid in assessing the reasonableness of the UAM-AERO emissions inputs, daily total emissions by source category (e.g., area source, elevated point source, mobile source) will be tabulated for all major species (e.g., PM_{10}, NMOC, CO, NO_x, SO_2, and NH_3) for all modeling days. Quality assurance procedures that will be used to ensure the consistency and accuracy of the emissions inventories generated with the SMOKE model will include documentation of major assumptions, careful accounting of emissions totals throughout the development process, verification of spatial distributions of emissions against known locations, and identification of missing or unreasonable data values. The emissions files will be tabulated, plotted and examined before UAM-AERO simulations are performed. In support of this QA analysis, the array of graphical and statistical procedures in ARC-INFO and PAVE will be used to summarize and display the temporal and spatial allocation of emissions estimates by source category.

3.6 Emissions Forecasting/Backcasting

Forecasting (or projecting) emissions estimates to future years, accounting for the effects of growth and emissions controls, is a key element of emissions modeling. In SMOKE, area source and point source emissions are projected with the control factor input files ACTRL and PCTRL which specify exactly what

controls are to be applied. These are then processed with control matrix construction programs CTLAMAT for area sources and CTLPMAT for point sources. Additionally, SMOKE introduces the concept of a control-report output file which reports the various controls which were applicable, as well as the precedence relationships among them (e.g., that MACT controls override RACT controls) for a user-selected set of sources.

For stationary source emissions projection, changes are typically based on projected employment by industry type and population growth estimates. Generally, these data sets are obtained from governmental agencies. For cases in which these growth factors do not apply (i.e., for a small source category), projected population growth or no-growth assumptions may be used. For future-year activity levels, the anticipated effects of controls are implemented via a user-input file that defines the portion of emissions remaining after control is implemented.

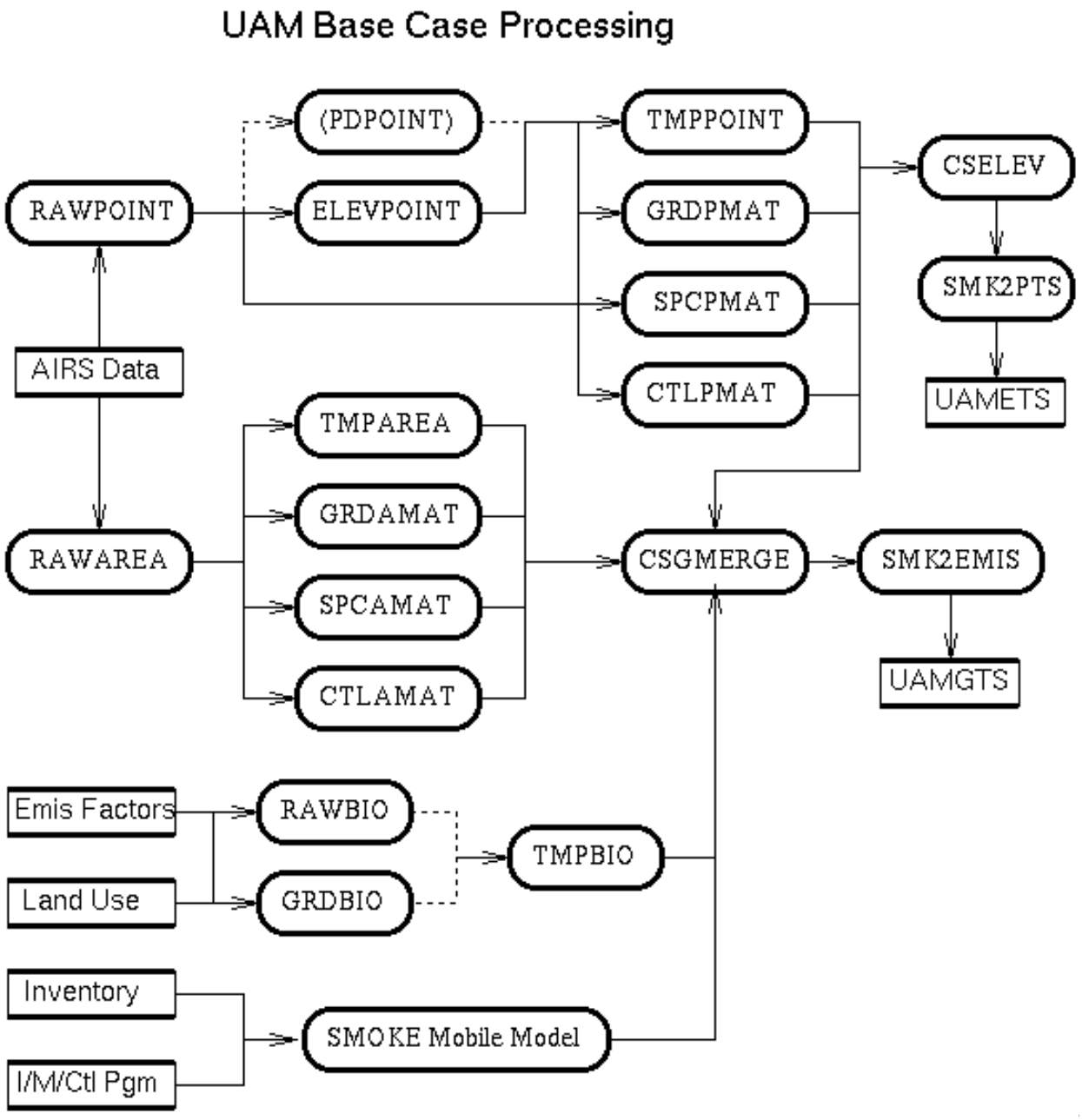


Figure 3-1a. SMOKE System Flow Diagram for Base Case Modeling

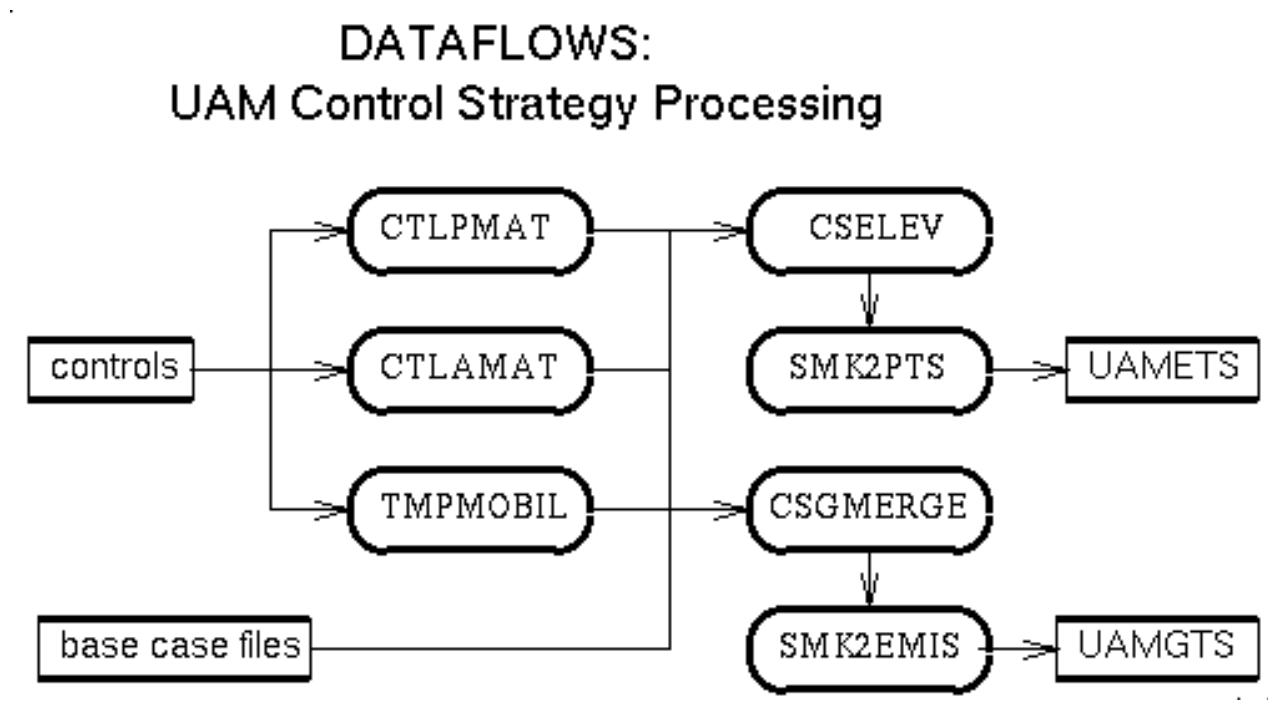


Figure 3-1b. SMOKE System Flow Diagram for Control Strategy Modeling

4.0 METEOROLOGICAL MODELING METHODOLOGY

The meteorological data and input preparation techniques for application of the UAM-AERO to the Wasatch Front area are described in this section. These inputs, involving the meteorological fields for the modeling episodes, will be prepared in accordance with the general guidelines established by the U.S. EPA for the regulatory application of gridded photochemical models (EPA, 1991).

4.1 Meteorological Data Base

All available meteorological data will be used in evaluation of the meteorological modeling. The following items are available through the University of Utah Department of Meteorology: GOES visible, infrared, and WV-channel imagery; Utah Mesonet observations; conventional soundings from SLC and other NWS sites; Dugway wind profiler; gridded observational analyses from NCEP; Rapid Update Cycle (60 km/3 h resolution); and the Eta model (80 km/12 h resolution). Meteorological data availability for input preparation are summarized in Table 4-1 and Figure 4-1.

The Utah Mesonet is a cooperative project between researchers at the University of Utah, forecasters at the Salt Lake City National Weather Service Office, and scientists at a variety of government and private institutions to collect and integrate data from all available meteorological networks over the intermountain west. During the PM_{10} episodes to be examined, data was collected and archived from 10 meteorological networks over Utah and surrounding states. This included observations from approximately 15-20 stations in Salt Lake and Utah counties, including observations taken from high elevation sites in the Wasatch Mountains. All of these stations report wind and temperature, while some report precipitation and sky cover information. Data from a network maintained by the Utah Division of Air Quality is also available and will be used for the project. If a 1999/2000 episode is used, the entire network of Utah Mesonet data will be available.

4.2 Meteorological Modeling

Given the complexity of the local mountainous terrain, in close proximity to two large bodies of water (Utah and Great Salt Lake), DAQ recommends the evaluation of a prognostic meteorological model to develop the meteorological inputs to the UAM-AERO. Specifically, the following approach is recommended:

- Scientists at the University of Utah Department of Meteorology and NOAA Cooperative Institute for Regional Prediction will be responsible for developing meteorological input data for the Urban Airshed Model. The effort will involve running a prognostic mesoscale model, the Penn State/NCAR mesoscale model (MM5) and its accompanying data assimilation systems. If funding permits, the Advanced Regional Prediction System (ARPS) will also be used to evaluate meteorological conditions in the Wasatch Front.

- The resulting datasets will be validated both objectively and subjectively. First, RMS errors will be calculated from available surface and upper air data. Then a subjective evaluation of boundary

layer and mesoscale circulation structure and evolution will be carried out. Based on these evaluations of model performance one system, or potentially a combination of analyses from the two systems, will be used for meteorological input to the UAM.

4.2.1 MM5 Prognostic Meteorological Model

The MM5 will be run for each event using 4 domains with an inner-grid that covers the UAM modeling region with a horizontal resolution of 2 km (Figure 4-2). Vertical resolution will vary from approximately 10 mb (40 m) in the Salt Lake Basin to around 50 mb in the middle and upper troposphere. The simulation will employ continuous multiscale data assimilation. This involves the assimilation of gridded regional scale analyses on the coarser resolution outer grids to constrain large scale error growth and observational nudging on the higher resolution inner grids in order to improve the mesoscale structure of the simulation. Analyses and observations for nudging will be provided by National Centers for Environmental Prediction Eta model operational analyses (available at 12 h resolution) and Utah Mesonet observations, respectively. Regional soundings and profiler observations from Dugway Proving Grounds (if available) will also be used. The primary objective of this work is to produce a four dimensional dataset that captures the observed evolution of each event as accurately as possible. Because of the length of each event, successive simulations may be used.

4.2.2 ARPS/ADAS Data Assimilation

Scientists at the University of Utah Department of Meteorology and NOAA Cooperative Institute for Regional Prediction have recently developed a data assimilation system based on the University of Oklahoma ADAS (ARPS data assimilation system; ARPS is an acronym for the Advanced Regional Prediction System, which is a mesoscale model). This system ingests a wide variety of data, including satellite and radar observations. Hourly three dimensional analyses at 1-km resolution will be generated using this system. Regional Rapid Update Cycle (RUC) analyses from NCEP or 1-h forecasts from ARPS will be used to provide a first-guess field for ADAS. If funding permits, the ADAS analysis will be used in conjunction with MM5 to provide inputs to UAM-AERO.

4.3 Meteorological Inputs to the Aerosol Model

The results of the MM5 and ADAS analyses will be used to create many of the meteorological input files to the UAM-AERO preprocessor routines. Figure 4-3 depicts the overall UAM-AERO modeling system. MM5 and ADAS data will be utilized in the "Meteorology" section of the routines. Since some of the 3-D variables require the DIFFBREAK file as input (the domain's layers are defined by the DIFFBREAK heights), the modeled meteorology cannot provide inputs directly to the UAM-AERO system but rather only to preprocessors which can allocate meteorological parameters to the appropriate UAM-AERO vertical layers. The prognostic modeled data will also be used to develop the DIFFBREAK file itself. These preprocessor inputs include three dimensional fields for wind, temperature, and water vapor on the UAM-AERO modeling domain. In addition, a two dimensional fog field will be created using standard National Weather Service observations and available satellite imagery. This file contains information about clear, hazy or foggy conditions in each horizontal grid cell in the first two vertical layers of the modeling domain. The MM5 output files will have to be processed to reflect the

UAM-AERO modeling domain, including the vertical structure of the UAM-AERO domain which is more coarse than the vertical structure of the MM5 domain. Figure 4-4 conceptually depicts an MM5 vertical structure in comparison to a UAM-AERO vertical structure. The influence of the DIFFBREAK height can be seen in that the calculation of each UAM-AERO vertical layer may depend upon different MM5 layers.

Table 4-1. Pollutants and Meteorology Measured at Air Monitoring Sites (August 1999)

ID	Monitor Site	PM_{10}	$PM_{2.5}$	CO	O_3	NO_2	SO_2	Pb	Met
7	Antelope Island								✔
8	Badger Island								✔
9	Beach				✔		✔		✔
13	Bountiful		✔	✔	✔	✔	✔		✔
19	Cottonwood	✔	✔	✔	✔	✔			✔
10	Grantsville		✔						✔
16	Hawthorne	✔	✔	✔	✔	✔			✔
20	Herriman				✔				✔
21	Highland				✔				✔
22	Lindon	✔	✔						✔
27	Logan	✔		✔	✔				
11	Magna	✔	✔				✔	✔	✔
28	Moab	✔							
1	North Ogden		✔		✔				✔
24	North Provo	✔	✔	✔	✔	✔			✔
14	North Salt Lake	✔	✔				✔		✔
4	Ogden	✔	✔			✔			
2	Promontory Point								✔
12	Salt Air								✔
23	South Orem			✔					
26	Spanish Fork		✔		✔				✔
15	State Street #3			✔					
6	Syracuse								✔
25	University Ave #3			✔					
3	Washington Blvd			✔					
5	Washington Terrace		✔	✔	✔				✔
18	West Jordan								✔
17	West Valley		✔	✔	✔				

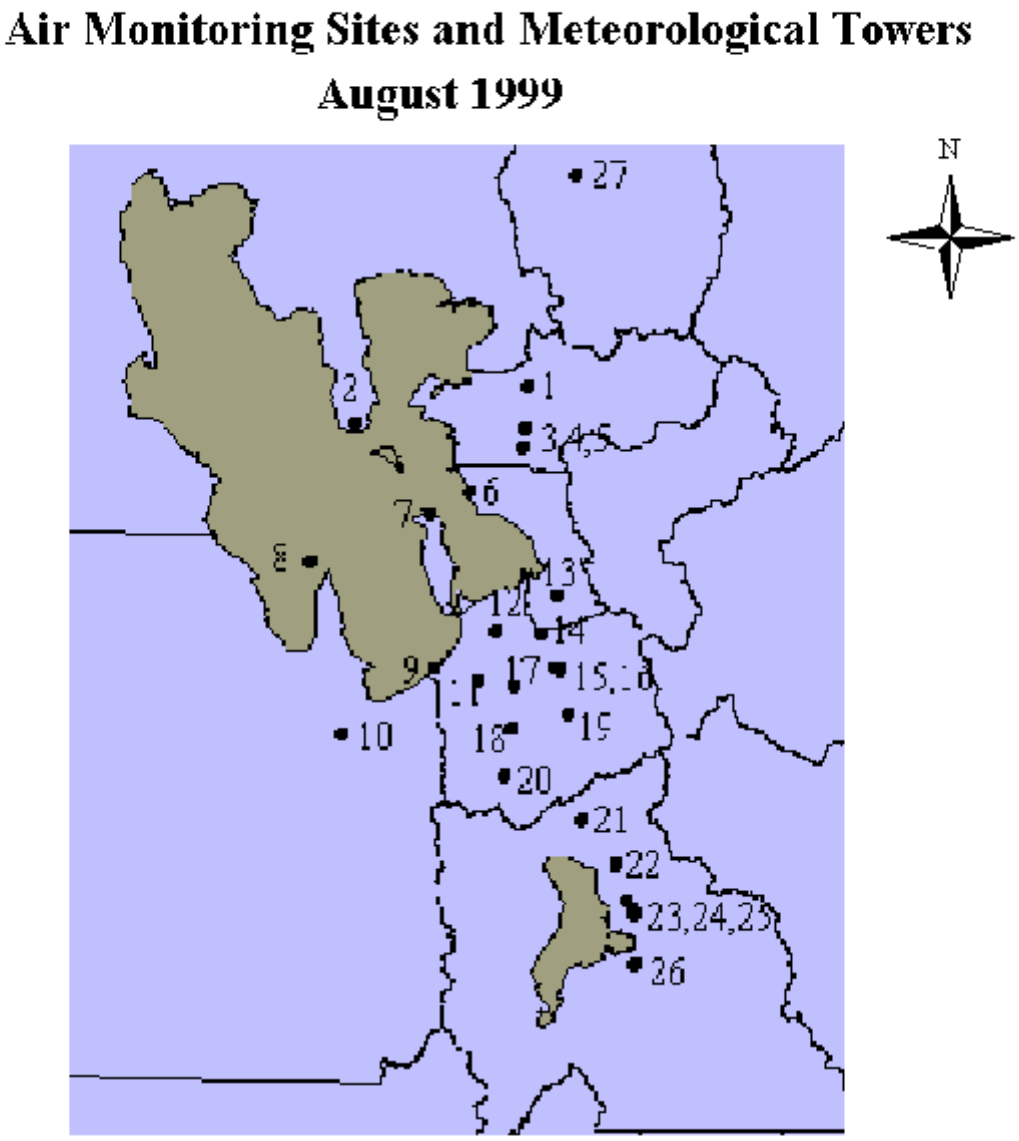


Figure 4-1. Air Monitoring Site Locations (August 1999)
See Table 4-1 for site names and pollutants and meteorology measured at each site.

Figure 4-2. **MM5 modeling domain.** The domains are labeled 1 through 4, 1 being the outermost coarse grid, and 4 being the innermost fine grid. The grid resolution is as follows: Domain 1 - 54 km; Domain 2 - 18 km; Domain 3 - 6 km; Domain 4 - 2 km. Domain 4 is just slightly bigger than the UAM-AERO 2 km modeling domain.

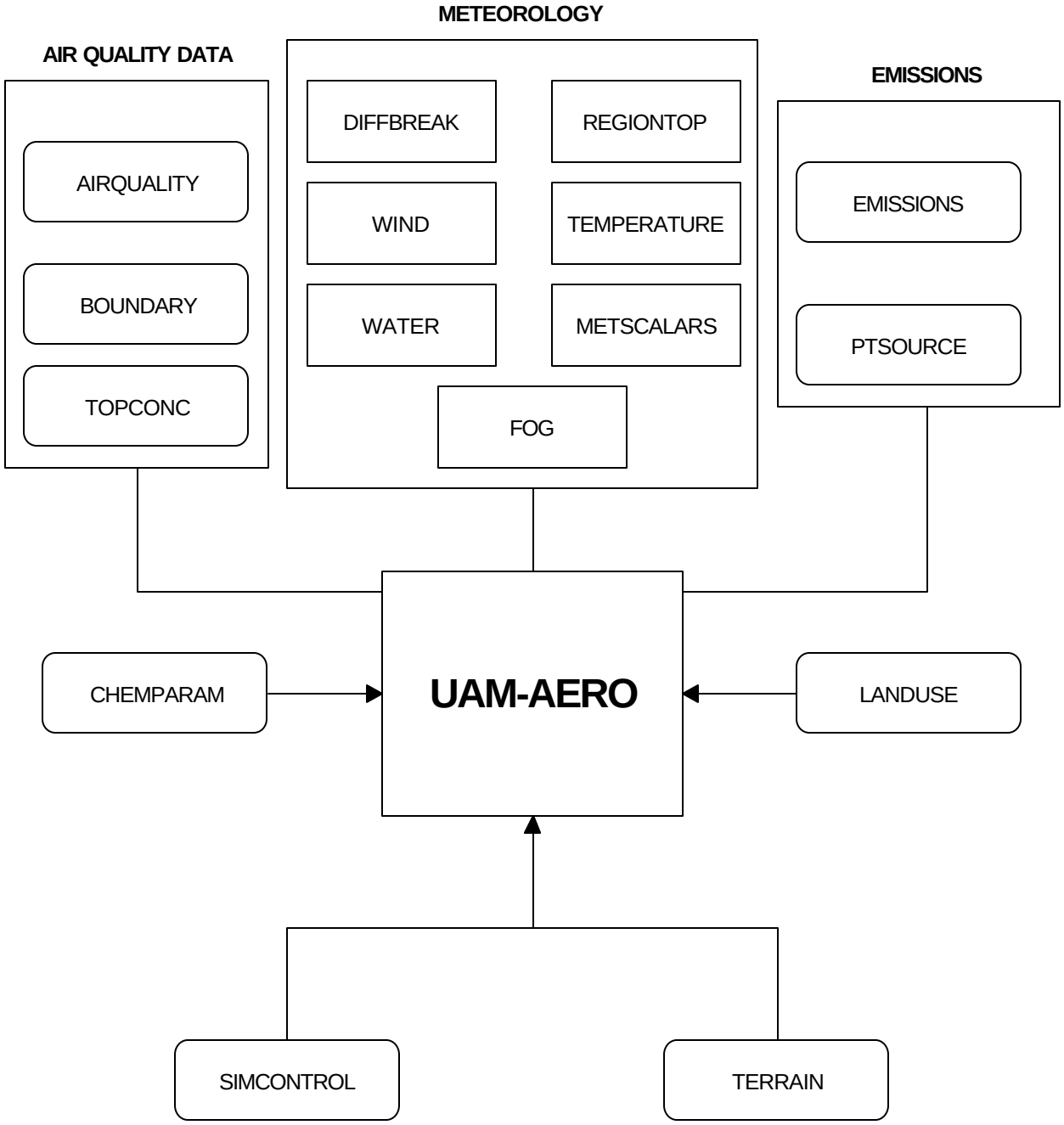


Figure 4-3. UAM-AERO Modeling System

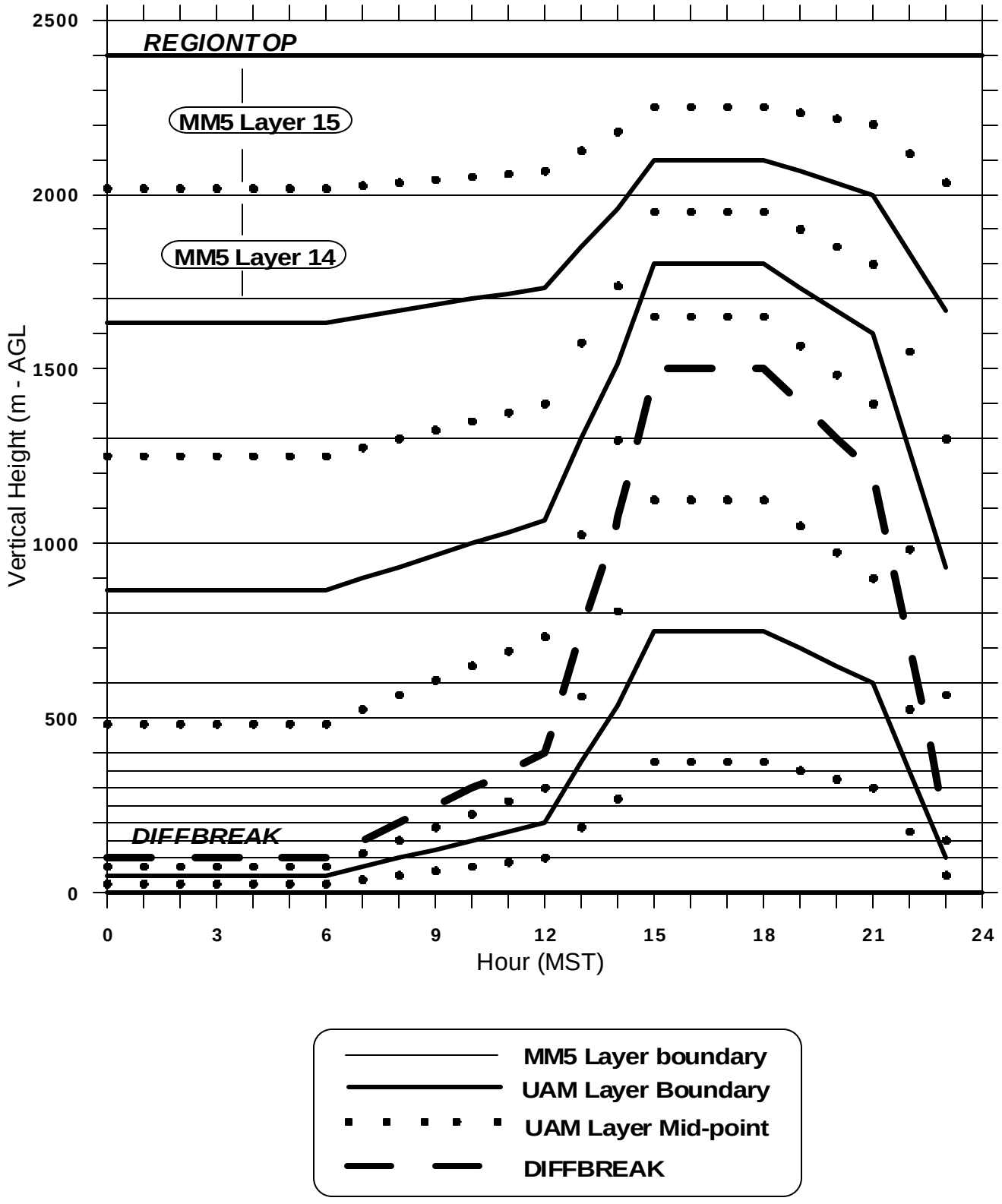


Figure 4-4. Schematic Comparison of MM5 and UAM-AERO Vertical Layers

5.0 AEROSOL MODELING METHODOLOGY

5.1 Air Quality Data Base

The bulk of the air quality data available for UAM-AERO application and evaluation will be obtained from the Utah Air Monitoring Center. Since 1996 the Air Monitoring Center's monitoring network has been enhanced. The air quality data bases have been improved using this monitoring network. These data have been obtained from various sources including the DAQ, the Aerometric Information Retrieval System (AIRS), the National Climatic Data Center (NCDC), the U.S. Geological Survey (USGS), the U.S. Forest Service (USFS), and several local and industrial sources. Land-use data for the preparation of gridded surrogates and the UAM-AERO land use file will be obtained from the USGS and the Utah Automated Geographic Reference Center (AGRC).

5.2 The Aerosol Dispersion Model (UAM-AERO)

The aerosol model to be used for the PM_{10} SIP modeling is the Urban Airshed Model with aerosol treatment employing CB-IV chemistry (UAM-AERO). The UAM-AERO is an Eulerian aerosol model that simulates the emission, transport, dispersion, chemical transformation, and removal of inert and chemically reactive species in the atmospheric boundary layer. The key feature of the UAM-AERO model is that it provides a common framework in which to evaluate relationships between ambient concentrations of both ozone and particulate matter (PM), and their precursor emissions. (Kumar and Lurmann, 1996; Lurmann, et al, 1997) Figure 4-3 presents the UAM-AERO system flow diagram.

5.2.1 Chemical Mechanism in UAM-AERO

The particulate mechanism in UAM-AERO is described in the "User's Guide to the UAM-AERO Model" (Kumar and Lurmann, 1996) and in Lurmann, et al, 1997. UAM-AERO simulates the effects of emissions injection, horizontal and vertical transport and dispersion, dry deposition, and chemical reactions on atmospheric concentrations of gaseous and particulate pollutants. The model quantifies the relationships between ambient PM concentrations and emissions of particles and of gaseous compounds that form secondary PM and/or affect the rate of secondary PM formation.

The emissions inputs to the model include six chemical components of particulates (elemental carbon, organic material, sulfate, sodium, chloride, and crustal material), and gaseous emissions of NO_x, SO_2, NH_3, VOC, and CO. The model predicts the following chemical components of PM as output: nitrate, sulfate, ammonium, sodium, chloride, elemental carbon, organic material, crustal material, and water.

UAM-AERO simulates the aerosol-size distribution as well as the chemical composition of the aerosols. Tracking aerosol size is important because the fate of particles in the atmosphere depends largely on their size. Particles grow and shrink in response to a number of physical processes and simulation of these dynamic processes is necessary to accurately predict the PM mass concentrations.

UAM-AERO also has a mechanism to simulate the effect of the presence of fog on gas and aerosol species. When haze or fog exist, the model allows particles to grow to sizes larger than 10 µm. Particle growth and shrinkage are determined by the amount of water transferred to and from the aerosol based on the equilibrium concentrations estimated by SEQUILIB for specific relative humidity, temperature, and aerosol chemical composition. Deposition of fog droplets is calculated using the same procedures used for other particles. In addition, aqueous-phase chemical reactions are simulated using the gas-phase chemistry operator.

5.3 UAM-AERO Input Preparation Procedures

The overall modeling system consists of a number of distinct preprocessing routines which produce files for input into the UAM-AERO main system. Figure 4-3 shows the UAM-AERO system in relation to each of the component preprocessors. Each of the input segments are discussed in this section.

5.3.1 UAM-AERO Region Definition

The proposed UAM-AERO modeling domain (Figure 2-10) consists of a 67 x 113 grid (east-west by north-south) with a 2 km resolution. This region contains the bulk of the emissions in the greater Ogden-Salt Lake City-Provo region. The 2 km horizontal grid resolution is higher resolution than has been used in previous modeling efforts in the Wasatch Front, but the increased resolution should provide valuable information regarding particulate issues in this area.

In the vertical, the following grid structure is proposed but will be finalized pending further review of the meteorological conditions during the modeled episodes.

- Five (5) vertical layers, two below the inversion and three above;
- A region top sufficiently high to contain all elevated point sources and the maximum inversion rise;
- A minimum cell height of 40 meters for layers 1 and 2 (below the inversion base); and
- A minimum cell height of 200 meters for layers 3 through 5 (above the inversion base).

5.3.2 AIRQUAL

The initial concentration fields for each episode will utilize air quality data collected within the Wasatch Front modeling domain. A distance-weighted interpolation will be used to generate gridded initial concentration fields. For concentrations aloft, an assumed vertical profile will be used to distribute the surface concentration estimates to UAM-AERO levels 2 through 5.

5.3.3 BOUNDARY

For inflow boundaries, hourly boundary conditions will be specified on the basis of observed air quality data at monitors. Where data are lacking, estimates of inflow boundary conditions will be based on

upwind emissions source region considerations. Along those boundaries through which pollutant transport is not a factor, clean boundary conditions representing background concentrations of the pollutants (EPA, 1991) will be used.

5.3.4 CHEMPARAM

The species, rate constants, and other parameters contained in this file will be based on the requirements of the UAM-AERO CB-IV chemical mechanism and EPA default values.

5.3.5 DIFFBREAK

A number of techniques are available for estimating the mixing heights for UAM-AERO applications. Due to the complexity of the study domain, particularly the close proximity of mountainous terrain and two large lakes, the prognostic meteorological model (MM5) will be used to produce meteorological inputs to the various preprocessors for mixing height estimation. Observations during the two 1996 episodes indicate mixing heights that generally vary from about 90 meters to 300 meters throughout the day (see Table 5-1 and Figure 5-1).

The University of Utah Department of Meteorology will incorporate the mixing height calculation technique into their interpolation methods in order to create a gridded mixing height field which is based on MM5 output.

5.3.6 METSCALARS

Meteorological data collected at the SLCIA and from the 1996 study sites will be used to estimate the spatially constant, temporally varying METSCALARS. These data include hourly values of atmospheric pressure and the exposure class (stability class). Because UAM-AERO has three-dimensional temperature and humidity fields, these values in the METSCALARS input file are dummy variables.

5.3.7 REGIONTOP

For each UAM-AERO modeling episode, the height of the top of the modeling region will be held constant throughout the simulation. This value will be based on the maximum mixing height for the modeling episode, as determined from the MM5 simulations and the ADAS analysis.

5.3.8 SIMCONTROL

The starting time for all UAM-AERO simulations will be 0000 MST and will run though 2400 MST on the last day. All other information contained in the SIMCONTROL file will remain constant from one simulation to another.

5.3.9 TEMPERATURE

Gridded temperature fields for the UAM-AERO application to the Wasatch Front Study area will be derived from MM5 modeling results incorporating observed meteorological data. Three dimensional temperature fields will be extracted from the MM5 output and then reformatted for input directly into UAM-AERO. These temperature inputs will be created by the University of Utah Meteorology Department in consultation with DAQ and DAQ's UAM-AERO contractor.

5.3.10 TERRAIN

Gridded land use data for the modeling region will be derived by combining 1:250,000 scale USGS data with a much finer resolution, 30 meter land use data set created by they Utah AGRC. The surface roughness and deposition velocities as a function of land use will be derived from studies performed by the Argonne National Laboratory, as summarized in the UAM-IV users manuals. The land use values proposed for the Wasatch Front are listed in Table 5-2.

5.3.11 TOPCONC

Because no aloft air quality measurements are available to formulate day-specific concentrations for the top of the modeling region, the TOPCONC pollutant concentrations will be specified after reviewing all available information on air quality aloft from applicable field studies.

5.3.12 WIND

Wind fields for the Wasatch Front region will be derived in a two step process. First, the MM5 prognostic meteorological model will be run. Subsequently, output from MM5 (which may or may not incorporate ADAS analysis) will be input to a customized preprocessor program. This program will interpolate the wind fields onto the UAM-AERO grid mesh and format the horizontal flow vectors into the form expected by the air quality model.

5.3.13 WATER VAPOR

Gridded water vapor fields for the UAM-AERO application to the Wasatch Front area will be derived from MM5 modeling results. The MM5 modeling will incorporate observed meteorological data. The processing of the water vapor fields is combined with the TEMPERATURE file preparation and is described in section 5.3.9.

5.3.14 FOG

An hourly, gridded two-dimensional fog field will be derived from meteorological observations and satellite imagery. This fog file will assign values for clear, hazy, or foggy conditions for every hour in each horizontal grid cell in the first two vertical layers of the modeling domain.

5.4 Quality Assurance of Model Inputs

The meteorological, air quality, and land-use inputs will be plotted and examined to ensure: (a) accurate representation of the observed data in the UAM-ready fields, and (b) temporal and spatial consistency and reasonableness. Note that the MM5 and/or ARPS wind fields will undergo an extensive evaluation using GIS displays. This evaluation will include analysis of surface meteorological parameters (wind speed, wind direction, and temperature) as well as meteorological parameters aloft at the upper air sounding sites.

	Episode 1				Episode 2			
Hour	Feb 06	Feb 07	Feb 08	Feb 09	Feb 12	Feb 13	Feb 14	Feb 15
0	127	131	204	177	127	131	206	179
1	118	146	202	164	118	146	202	177
2	111	112	173	158	111	117	173	162
3	131	164	139	206	131	167	139	146
4	166	168	140	217	166	168	146	156
5	147	173	179	218	147	173	186	175
6	132	199	243	193	132	198	249	185
7	136	171	243	194	136	171	245	159
8	164	174	232	185	164	171	233	136
9	211	165	130	182	211	163	133	150
10	205	234	166	187	205	234	173	175
11	248	271	235	168	248	270	238	211
12	245	200	320	213	245	199	321	226
13	271	171	297	269	271	173	297	238
14	254	147	261	361	254	151	261	246
15	266	198	274	360	266	202	275	250
16	239	168	283	316	239	171	279	228
17	161	144	254	254	161	148	250	167
18	127	118	196	196	127	123	191	116
19	96	149	151	204	96	156	151	145
20	126	161	134	257	126	166	133	181
21	101	177	120	333	101	182	117	183
22	96	109	108	414	96	112	104	100
23	94	88	98	431	94	90	94	60
Minimum	**94**	**88**	**98**	**158**	**94**	**90**	**94**	**60**
Maximum	**271**	**271**	**320**	**431**	**271**	**270**	**321**	**250**

Table 5-1. Estimated DIFFBREAK for PM_{10} Episodes

Table 5-2. Land Use Categories

Category	Land Use
1	**Urban land**
2	**Agricultural land**
3	**Range land**
4	**Deciduous forest**
5	**Coniferous forest**
6	**Mixed forest including wetland**
7	**Water, both salt and fresh**
8	**Barren land, mostly desert**
9	**Nonforested wetland**
10	**Mixed agricultural and rangeland**
11	**Rocky open areas with low-growing shrubs**

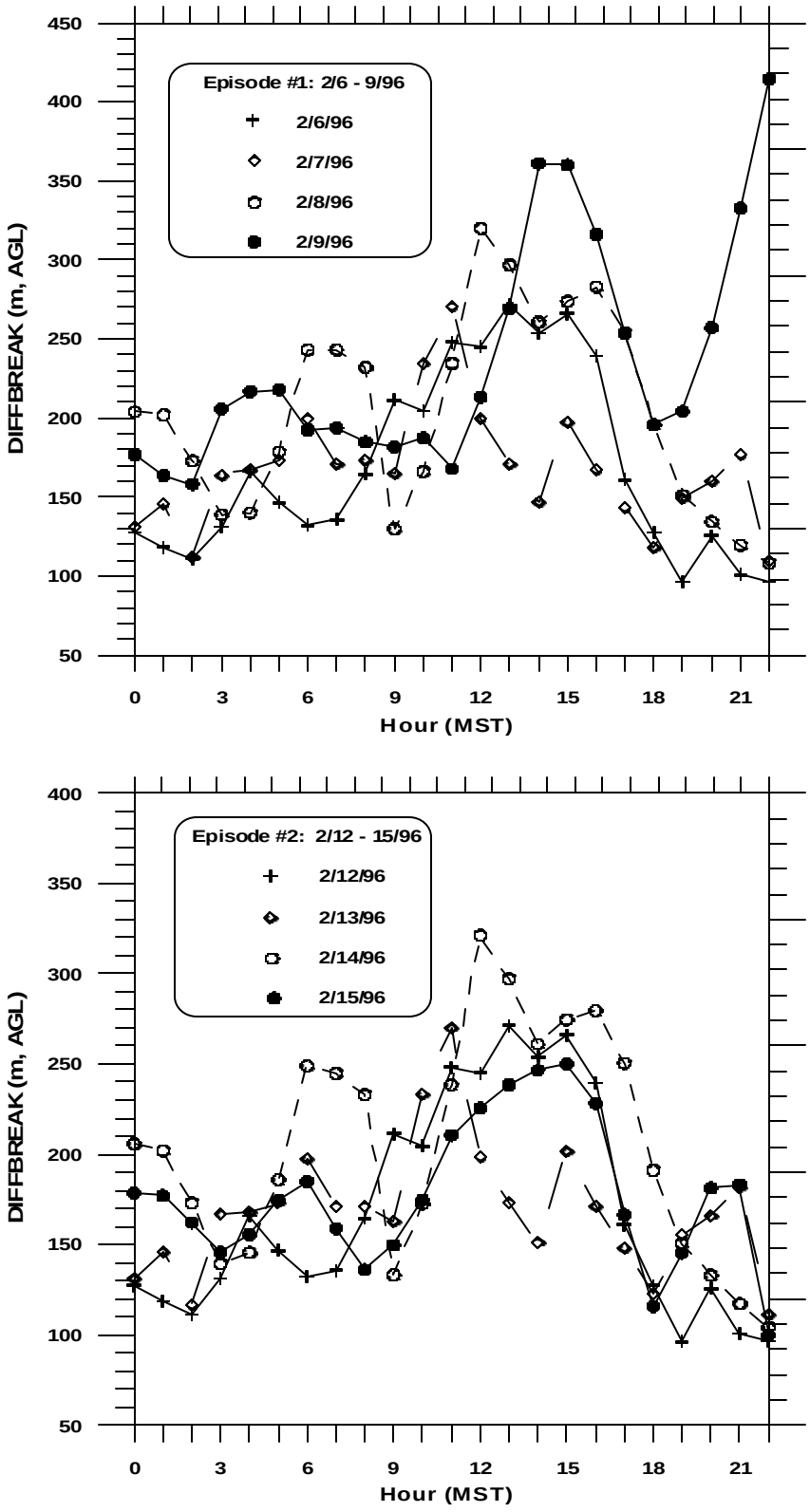


Figure 5-1. Estimated DIFFBREAK (mechanical) for February 1996 Episodes

6.0 MODEL PERFORMANCE EVALUATION

Introduction

Because aerosol modeling is still in its infancy relative to photochemical ozone modeling, official guidance on model performance evaluation (MPE) is not available. The EPA has developed a guidance document for ozone model performance evaluation (U.S. EPA, 1991) that suggests specific tests and comparisons, recommends graphical methods for use in interpreting and displaying results, and identifies potential issues or problems that may arise. Another document titled "Improvement of Procedures for Evaluating Photochemical Models," (Tesche et al., 1990) provides a comprehensive discussion of MPE procedures and issues, and significantly influenced the EPA guidance document. More up-to-date guidance on ozone modeling (U.S. EPA, 1999a) is also available from EPA in draft form and includes suggestions on performance evaluation. While these documents focus on model performance for ozone, the basic MPE concepts are applicable to aerosol models. An EPA concept paper (U.S. EPA, 1999b) also provides some insight, albeit for modeling the fine fraction, on evaluating model performance.

Photochemical model performance evaluation is a process in which statistics play a crucial role, but are often not sufficient to tell the whole story. The evaluation process consists of:

- developing a plan or protocol for assessing the extent to which the modeling system emulates the real atmosphere;
- carrying out the appropriate simulations;
- comparing model estimates with observations;
- attempting to ensure that potential compensating internal errors do not exist or are minimized;
- identifying causes of model and/or database inadequacies;
- correcting the inadequacies where possible; and
- re-evaluating model performance.

The objective of this MPE is to determine if the UAM-AERO simulations performed for this study can be used to demonstrate attainment of the National Ambient Air Quality Standards (NAAQS) for PM_{10}. In performing the evaluation we will try to answer the following questions:

- How close does the model simulate observed concentrations?
- What biases are exhibited by the model? What are the causes?
- What are the model's sensitivities and can they be quantified?
- Does the model respond, in direction and magnitude, to emissions changes in such a way that enables decision-makers to confidently use the model for policy development?

It should be noted that a prerequisite for model performance evaluation is thorough analysis of the air quality data to be used in the analysis in order to characterize the features of the data that need to be reproduced in the models. These analyses include not only the routine summary statistics and distributions for each station, but also comparisons of the spatial and temporal characteristics at different sites.

With photochemical models such as the UAM-AERO, the atmospheric diffusion equation is numerically integrated over time and the model estimates for a specific hour and location are not independent of the model predictions for other hours and locations. The lack of independence occurs because the models' calculations depend on the previous hour's concentrations. Thus, there is a need to examine the model performance (bias and error) for all hours of the day, as well as for the hours and locations where the highest concentrations were observed. Because of the limited amount of data available for the episodes being considered, this type of examination may be difficult. If a model performs poorly for an hour before or an hour after a peak hour (but not at the peak hour), the simulation may be considered flawed because it did not simulate the processes leading up to and following the maximum concentration well. Other concerns are that photochemical model applications derive their credibility from not only the model performance statistics for the key product species (e.g., ozone, sulfate, or nitrate), but also the accuracy of the (1) predicted spatial, diurnal, and temporal (day-to-day) patterns of concentrations and (2) precursor species concentrations. Often, the results from each day of a photochemical model simulation are considered as independent predictions, even though technically this is not correct.

In this chapter we discuss methods for performing model performance evaluations and issues unique to evaluating aerosol model performance for the PM_{10} study. We describe the specific set of MPE procedures that will be applied to the UAM-AERO simulations performed for this study. We will also propose how the model results may be used, depending on the results of the MPE.

Model Performance Criteria for this Study

There are no universal acceptance criteria in photochemical modeling. Multiple statistics are used together with graphical displays to evaluate photochemical models because no one measure is adequate for characterization of performance. An attractive approach for determining "acceptance" of a model is for it to be derived from a lack of rejection in a series of planned tests. Tentative acceptance can be the result of many "nonrejections" in a prescribed evaluation process where both statistical comparisons with observed concentrations and graphical evaluation of predicted and observed patterns are considered. Acceptance is tentative because we can never have full information; rather, evidence builds to the point where we become comfortable with the prospect of a model being judged adequate in light of available information. Where possible, rejection criteria should be specified for all phases of testing.

A common problem in urban and regional modeling is that the model generates spatial patterns of pollutants that may be similar to the observed patterns. However, they may be shifted in time and/or space (elongated or broadened). Pattern recognition may be useful for analysis of spatial and temporal patterns. The classical statistical approaches to MPE do not provide sufficient information on the similarity of the spatial patterns, which could be useful in assessing performance. Because pattern recognition software has not been sufficiently tested for use with air quality data and there is little observational data available, we will rely upon subjective pattern recognition in this MPE. Emphasis will be placed on graphical analyses and evaluations will rely upon the modeling team's scientific understanding of the processes responsible for aerosol formation in the study region.

Multi-pollutant evaluations are particularly important for evaluating the performance of photochemical PM models. The same statistical measures of performance are generally used for all species, however, the criteria for rejection as well as the importance of certain measures may differ. **Table 6-1** lists species that should be considered in evaluating aerosol models. Because of data limitations, the species, which will be evaluated in this project, are those discussed in Table 6-3. Comparisons should be made for the major precursors and products. Clearly, reactive models that simulate precursor and product species well are much less likely to be flawed than models that only simulate a single product species well. Often, the observational databases lack sufficient species to carry out multi-pollutant evaluations, which is likely to be the case in this study.

Table 6-1. Candidate chemical constituents for aerosol model performance evaluation.

Particulate Matter	Other Constituents
$PM_{2.5}$ Mass	SO_2
PM_{10} Mass	NH_3
$PM_{2.5}$ SO_4	O_3
PM_{10} SO_4	NO
$PM_{2.5}$ NO_3	NO_2
PM_{10} NO_3	NO_y
$PM_{2.5}$ NH_4	VOCs
PM_{10} NH_4	PAN
$PM_{2.5}$ OC	HNO_3
PM_{10} OC	
$PM_{2.5}$ EC	
PM_{10} EC	

For evaluating performance of an aerosol model, such as UAM-AERO, chemical composition and size distribution of the aerosols should be considered. Evaluation of aerosol mass alone is not sufficient. If there are insufficient chemical- and size-resolved observations for the episode being modeled (as is the case in this study), it may be possible to use data from other periods in a quasi-objective manner. However, care must be taken to ensure that the data used are reasonably representative of the type of episode being modeled.

Photochemical aerosol modeling is more uncertain than photochemical ozone modeling for many reasons, which include:

- There are greater uncertainties in emission inventories for particulate matter
- Less is known about the physical and chemical processes contributing to aerosol formation and growth
- Observations of aerosols are more uncertain than observations of ozone
- Fewer observations are available to understand the spatial, chemical, and size distribution of aerosols in the ambient atmosphere and to use in model performance evaluation

This last point is particularly important. If we had only one observation of 24-hour average PM_{10} mass and could get perfect statistical performance at that location, there would still be a high level of uncertainty in the model's ability to correctly predict the response of PM_{10} formation to changes in the emission inventory. Only by making sure the model performs well for many locations and many predicted variables do we reduce uncertainty and gain confidence in the model's predictive ability. In the case of this PM_{10} modeling study, speciated data exist for only two days with virtually no temporally allocated measurements.

Much of our community's experience in model performance evaluation has been with ozone. Historically, we have used photochemical ozone models to demonstrate attainment of the ozone NAAQS in an absolute sense. An absolute attainment demonstration is an approach that relies on verification that the model is performing within statistical limits determined by EPA. If the model performs to these standards, then the absolute values obtained from the base case and future year scenarios are used to evaluate whether a future year control strategy is sufficient for an area to attain the NAAQS. Typically, extensive field study data are used in model-input preparation and MPE for an absolute attainment demonstration. Unfortunately, we do not have extensive meteorological or air quality data to support an absolute attainment demonstration for the Wasatch Front PM_{10} aerosol modeling application.

Aerosol modeling is currently more uncertain than ozone modeling. Thus, we are unlikely to reach a level of confidence with aerosol modeling that will allow us to use it in an absolute sense. However, there may be cases where an aerosol model significantly under- or over-predicts particulate matter concentrations but the results of the MPE convince us that it is capable of predicting the correct response to emission changes. In that case it may be possible to use the model predictions in a relative sense. Relative reduction factors similar to those proposed in EPA's draft guidance on ozone modeling (U.S. EPA, 1999a) could be generated for the particulate matter components.

Because of the uncertainties associated with aerosol modeling, we propose two levels of testing and use for UAM-AERO. At the highest level, we propose tests and criteria that are comparable to those applied to ozone modeling applications. If the model performs well at this level, it would be reasonable to use the model in an absolute attainment demonstration. The rejection criteria at this level are summarized in **Table 6-2**. The following section on model performance evaluation methods and issues provides a detailed discussion of the statistical measures, graphical procedures, and sensitivity analyses that are summarized here.

Table 6-2. Rejection criteria for UAM-AERO use in an absolute attainment demonstration.

Tests	Rejection Criteria
Statistical	Statistics for 1-hr and 24-hr averaged $PM_{2.5}$ and PM_{10} (mass and chemical components), ozone, NO, NO_2, SO_2, NH_3, HNO_3, and VOCs are worse than EPA's ozone model performance criteria: • Normalized Mean Bias greater than +/- 15 percent • Normalized Mean Error greater than 35 percent • Unpaired Peak Prediction Accuracy greater than 20 percent Where bias and error are calculated for cases when the observed concentrations are greater than or equal to 10 percent of the maximum observed concentration during the modeled episode for each species.
Graphical	Modeled and observed species for the episode are not chemically, spatially, and/or temporally consistent.
Sensitivity	Responses for important secondary species inconsistent with our understanding of the processes leading to their formation.
Data	Type and/or quantity insufficient to perform statistical and graphical tests for all species indicated.

Based on the preliminary review of data available for evaluating the candidate episodes, we expect that, based on the data test, it will be difficult to use UAM-AERO in an absolute attainment demonstration. There may be insufficient data to carry out the detailed statistical and graphical evaluations proposed. The alternative is to use UAM-AERO to calculate relative reduction factors for use in the attainment demonstration. This approach is discussed in detail in the Attainment Demonstration chapter. **Table 6**-3 provides a summary of observations expected to be available for the evaluation of the candidate episodes.

Table 6-3. Observations available for the model performance evaluation.

Constituent	Averaging Time	Sampling Method
This table is to be completed when STI's review of available data is finalized.		

With data availability in mind, we are proposing performance criteria for the relative use of UAM-AERO. The criteria are less stringent than those for use in an absolute attainment demonstration. However, they require that the tests provide consistent evidence that the model is capable of correctly predicting the response of PM_{10} concentrations to changes in the emission inventory. Because of data limitations, the evaluation at this level will be more subjective and rely heavily on the modeling team's scientific understanding of aerosol formation and the model's ability to replicate important processes in this formation. **Table 6-4** summarizes the criteria that we will use to reject or accept the use of UAM-AERO for calculating relative reduction factors to use in the attainment demonstration.

Table 6-4. Rejection criteria for UAM-AERO in a relative attainment demonstration.

Tests	Rejection Criteria
Statistical	Statistics for 24-hr average chemical components of PM_{10}: • Normalized Mean Bias greater than +/- 50 percent • Normalized Mean Error greater than 50 percent Where bias and error are calculated for cases when the observed concentrations are greater than or equal 10 percent of the maximum observed concentration for each species. The differences between predicted and observed PM_{10} chemical component fractions are subjectively determined to be significant, and cannot be explained or significantly reduced through diagnostic analysis. Significant differences in the relative contributions of primary and secondary PM_{10} exist between observations and predictions.
Graphical	Modeled and observed species for the episode are not spatially and/or temporally consistent. Diurnal variation of the predicted sum of nonvolatile PM components is not consistent with TEOM observations. Observations and predictions of primary and/or secondary species appear spatially uncorrelated and the lack of correlation cannot be explained. Spatial and/or temporal differences can be explained but indicate significant problems with the meteorological, emissions, or other inputs to the model.
Sensitivity	Response for secondary species is inconsistent with our understanding of the processes leading to their formation as described by a conceptual model developed in the scoping study. Initial or boundary conditions dominate model predictions of primary and/or secondary species. Model predictions of secondary species are unresponsive to changes in precursor emissions.
Data	Type and/or quantity are insufficient to perform statistical and graphical tests indicated above.

It must be stressed that these rejection criteria may change as we carry out the evaluation. In this type of evaluation where data are limited, the process, rather than specific criteria, leads to rejection or acceptance. The process will be an iterative one in which we first identify failures model performance and then use the information obtained in our analysis to improve the model configuration or inputs. We would then rerun and re-evaluate model. Final rejection of the modeling would only come if, considering schedule and resources, all reasonable improvements are exhausted. Because the evaluation will be carried out by chemical component, performance for primary and secondary PM_{10} may be accepted or rejected independently.

Failure at this level would be the basis for abandoning the use of UAM-AERO as the sole component of the attainment demonstration. In that case, speciated rollback in conjunction with information garnered from the UAM-AERO modeling process will be used as a fallback approach. Chapter X provides a description of the speciated rollback method that will used in this study.

In addition to evaluation of model results in terms of the above rejection criteria, base case model results must also be examined in terms of diagnosing the model's limitations. Examples of some potential model limitations are:

- inability of model to accurately treat light and variable winds which may lead to anomalous concentrations in areas of wind convergence;
- inability of model to trap pollutants within the inversion layer due to terrain following coordinate system, etc.

The process of understanding the limitations of the base case modeling runs will inform our performance criteria decisions.

Model Performance Evaluation Methods and Issues

In this section, we discuss how a model performance evaluation would be carried out for an absolute attainment demonstration and what problems are likely to be encountered in a practical evaluation. This is an idealized view of methods and criteria, some of which are not applicable to the PM_{10} aerosol modeling study because of insufficient data.

Statistical Evaluation

To quantify base-case model performance, selected statistical calculations are prescribed to compare observed and simulated pollutant species concentrations at monitoring sites for which valid, representative data are available (Tesche et al., 1990). Simulated pollutant concentrations for each monitoring site should be calculated by linearly interpolating pollutant concentrations from the center of each of the four adjacent grid cells. All statistics should be calculated for each monitoring site for which observed concentrations are available, for each county, and for all monitoring sites within the modeling domain. Statistics will be calculated for all chemical species for which observations are available. Three statistical measures of model performance are recommended in the existing EPA guidance document.

1. Mean normalized bias (NBIAS in percent) where N includes all of the predicted (Pred) and observed (Obs) concentration pairs with observed concentrations above a threshold concentration from all stations in a region (or subregion) on a given day. Note the bias is defined as a positive quantity when the model estimate exceeds the observation.

$$NBIAS = \frac{100}{N} \sum_{i=1}^{N} \frac{(Pred^{i}_{x,t} - Obs^{i}_{x,t})}{Obs^{i}_{x,t}}$$

2. Mean normalized error (NERROR in percent)

$$NERROR = \frac{100}{N} \sum_{i=1}^{N} \frac{|Pred^{i}_{x,t} - Obs^{i}_{x,t}|}{Obs^{i}_{x,t}}$$

3. Accuracy of daily maximum concentrations at the station with the highest observed concentration unpaired in time (APEAK in percent)

$$APEAK = 100\left(\frac{\text{Max } Pred_{xmax} - \text{Max } Obs_{xmax}}{\text{Max } Obs_{xmax}}\right)$$

These three statistics cover the basic concerns for model bias and error for all hours with concentrations above a background concentration and for model bias in the maximum concentration, which is particularly important for regulatory purposes for ozone.

Additional statistics that we have found useful and have included in prior evaluations are:

- Mean absolute bias
- Mean fractional bias
- Mean absolute error
- Mean fractional error
- Average accuracy of the daily maximum concentrations paired in space, unpaired in time
- Peak accuracy paired in space
- Peak accuracy paired in space and time
- Correlation of all hourly (or multi-hour) concentrations
- Correlation of daily maximum concentrations

These performance measures provide additional information regarding model performance and allow one to make statistical statements concerning the bias and error on an absolute basis and the amount of the observed variance (R^2) explained by the model predictions. The fractional bias and error are particularly useful for precursor species where large residuals often make it difficult to interpret the normalized and absolute bias alone. Examination of the peak accuracy paired in space and paired in space and time also provides insight to the spatial and temporal displacements of peaks that are common in photochemical simulations. Small displacements are expected because of uncertainties in the wind fields, but large displacements are symptomatic of problems. Often the three measures of bias or error (mean absolute, mean normalized, and mean fractional) provide redundant information; however, they still need to be examined for the occasional cases where they show significant differences and illustrate problems in the simulations.

In past air quality modeling studies, emphasis has been placed on statistical evaluation, as described above. However, in this study there will be only a limited number of observations with which to evaluate model performance. Therefore, we must take care not to overestimate the significance of these statistics.

Graphical Evaluation

Spatial pattern comparisons of predicted and observed ozone concentrations will be included as a performance measure. Time-series plots and contour plots (ground-level isopleths) are very useful for displaying simulation results. Graphical analysis procedures to be used include:

- Time-series plots comparing observed and simulated pollutant concentrations for all monitoring stations within the modeling domain. Observed values will be represented as points and simulation results as a line.
- Time-series plots comparing observed concentrations with the minimum and maximum simulated concentrations in surrounding grid cells of a monitoring site
- Contour plots showing simulated pollutant concentrations and observed concentrations for each hour and/or multi-hour interval.
- Tile plots showing differences between observed and simulated concentrations
- Tile plots showing differences between sensitivity simulations (see next section) and base-case simulations.
- Plots of the frequency distribution of residuals (differences between hourly observed and predicted concentrations).
- Plots of residuals versus observed concentrations.
- Scatter plots of observed versus predicted hourly concentrations.

Sensitivity Analysis

We define sensitivity analysis as an evaluation of the response of the model variations in one or more of the model inputs. The purpose of sensitivity analysis is to determine which of the model inputs have significant impact on model output. Sensitivity analysis serves as a check on the air quality simulation by ensuring that the model behavior adequately reflects understood atmospheric and chemical processes.

The response of the photochemical grid model, represented by simulated pollutant concentrations at selected monitoring sites, will be evaluated as input boundary conditions and emissions rates are varied. Possible sensitivity simulations include:

- Zero initial conditions
- Zero boundary conditions
- Zero anthropogenic emissions
- Zero and double particulate matter emissions
- Zero and double ammonia emissions
- Emissions reductions of 50 percent in nitrogen oxides
- Emissions reductions of 50 percent in reactive organic gases
- Emissions reductions of 50 percent in nitrogen oxides and in reactive organic gases
- Zero and double mobile source emissions

- Zero surface deposition

For each input scenario, graphical and statistical analyses will be generated.

Software

The statistical and graphical analyses for this MPE will be generated using the Package for Analysis and Visualization of Environmental data (PAVE) (Thorpe et al., 1996), ArcInfo, and the Model Performance Evaluation, Analysis and Plotting Software (MAPS) (McNally and Tesche, 1993).

PAVE will be used for graphical exploration model simulation results and producing tile plots. A set of utility programs, developed at the California Air Resources Board, will be used to extract data from the UAM-AERO output files for use with ArcInfo and other analysis tools. The MAPS system includes all of the recommended statistical and graphical analysis methods suggested for photochemical models by Tesche et al., (1990) and will be used by STI scientists in their evaluations of model performance.

7.0 PM_{10} ATTAINMENT DEMONSTRATION

Although Salt Lake and Utah counties have not violated the PM_{10} NAAQS since 1995, there still remains the need to demonstrate that attainment will be maintained in future years notwithstanding continued urban and industrial growth in the region. Below are summarized technical approaches in the development of future year baseline and control strategy emissions inventories and in the estimation of boundary conditions for model application. Additionally, we will describe the procedures we will use to demonstrate attainment.

7.1 Development of Future Year Emissions

The first step in evaluating future emissions control scenarios is the development of future year emissions inventories. Base year (i.e., 1996) modeling emissions must be projected to some future baseline year (i.e., 2007, 2017, etc). The future year projected inventory(s) reflects the net effect of mandated controls and growth projections for each source category. The methodologies used to develop future year emissions projections should be consistent with EPA guidance. The discussion below is provided as a general example of how future year inventories have been completed in the past in other areas. Certainly, these procedures will need to be refined considerably to account for the local source patterns in the Wasatch Front area and specific EPA guidance.

For point sources, two options exist for estimating future activity levels. The more rigorous approach involves obtaining information from individual facilities on projected industrial expansion or new construction. This information is usually obtained by contacting the facility management. Important considerations in projecting future activity levels for individual facilities include whether projected increases will occur at existing or new locations (necessary for spatial allocation of emissions), and when expansion or new construction is scheduled for completion. If proposed expansion or construction is to occur at a new site, point source records, estimated emissions, stack parameters, operating schedules, etc. must be generated for each source anticipated for the new facility. Such projections are often difficult, if not impossible, to obtain. The more common approach is to scale emissions levels from existing sources based on aggregate industrial activity level projections. Sources of aggregate projected activity levels include local Metropolitan Planning Organizations (MPOs) and the Bureau of Economic Analysis (BEA), which regularly publish industrial activity projections for both state and MSA levels by two-digit Standard Industrial Code (SIC) classification. Because this second method is based upon national trends, it represents the opposite end of the spectrum in terms of data resolution. The approach which will be used for this study represents the middle ground in that the projection of baseline inventories will be based on economic and population growth estimates from the Utah Office of Planning and Budget and the local MPOs.

Area source emissions can be projected to future levels by source category using a combination of projected population and industrial activity data, either from local agencies (if available) or the BEA. Transportation modeling outputs for future years as well as projected VMT levels will be required for constructing future baseline mobile source emissions estimates. These also, will be based upon growth projections provided by the MPOs.

Upon completion of the projected emissions inventory, the aerosol model will be run to identify areas in which projected growth and control will result in exceedances of the PM_{10} NAAQS. Sensitivity studies can be used to identify which source categories are likely to contribute to exceedances of the NAAQS. A control strategy committee will incorporate this information into the development of emissions reductions strategies. These control strategies will be modeled to evaluate their effectiveness in meeting the PM_{10} NAAQS standard. Because of the complexity of PM_{10} source categories, specific control strategies will require detailed discussion and evaluation among the control strategy committee.

Current EPA guidance requires that future control efficiencies include a "rule effectiveness factor" that accounts for less than full compliance. To estimate the effectiveness of a regulatory program, several factors must be considered, including the nature of the regulation, the nature of the compliance procedures, the performance of the source in maintaining compliance over time, and the performance of the implementing agency in ensuring compliance. States are given the option of deriving local category-specific rule effectiveness factors, which are subject to EPA review, or applying EPA's factor of 80%.

The emissions totals by source category must be compared with baseline emissions. Different plots can be used effectively to examine differences between the baseline and control strategy emissions inventories.

7.2 Development of Future Year Boundary Conditions

In many urban areas throughout the U.S. development of the inflow boundary conditions is a crucial and often uncertain component of the future year modeling analysis. The Wasatch Front region has essentially no historical or special studies pollutant concentration data along its upwind boundaries nor have there been any regional scale modeling studies that might provide estimates of boundary conditions. Offsetting this lack, however, is the fact that there is little major source activity upwind of the region. Accordingly, while there will no doubt be some uncertainty in estimating the future year concentrations of PM_{10} precursors along the UAM-AERO's inflow boundaries, these concentrations are likely to be fairly close to rural background levels. Thus, the effects of uncertainties in boundary conditions in future years will be less than in other areas of the country. Nevertheless, since there will be some uncertainty in boundary conditions for future years, it is recommended that this be addressed through the use of model sensitivity/uncertainty simulations.

7.3 Attainment Demonstration

The PM10 attainment demonstration will consist of a multi-component process. If the Model Performance Evaluation demonstrates adequate model performance, then a relative reduction factor method, in conjunction with a hot spot analysis, will be used to demonstrate attainment. If the model does not perform adequately, then we will use speciated linear rollback to demonstrate attainment.

7.3.1 The Use of Relative Reduction Factors for Attainment Demonstration

Central to using the relative reduction factor (RRF) approach with an air quality model is an acknowledgment of the uncertainty inherent in the *estimated* PM_{10} concentrations from the model. The use of RRF attempts to anchor uncertain model estimates to actual monitored values.

Consider a hypothetical situation with one monitor. The high value monitored at this location during a PM_{10} episode is 165 Fg/m^3. To evaluate the effectiveness of a potential control strategy with the air quality model one would first run the model for the base case. Assume the model performs acceptably but has a bias towards over-predicting PM_{10} at this monitor location. The model estimate for the grid cell containing the monitor is 185 Fg/m^3; a 20 Fg/m^3 overestimation at that location.

The model is now run for a future year, 2003, with an adjusted emissions inventory based on a set of control strategies. The model estimate for that same grid cell is now 167 Fg/m^3, a 10% reduction indicating a positive response to the control strategy.

The modeled attainment test, a quantitative measure of the effectiveness of the SIP control strategy, is passed when:

155 > (RRF * monitored value).

Where 155 = PM_{10} NAAQS (rounded to the nearest 10th) and

$$RRF = \frac{\text{modeled future year concentration}}{\text{modeled base year concentration}}$$

In this example:

(167/185) * 165 = 149

149 < NAAQS, thus the modeled attainment test is passed.

The remainder of this section explains the development of site-specific, component-specific RRF for the Utah PM_{10} SIP.

Developing the RRF

In section 6.0 it is proposed that if model performance does not meet criteria which will enable its use with a high degree of confidence a second, more subjective, performance evaluation will be undertaken. If model performance under these less stringent criteria is deemed acceptable the technical team will complete a modeled attainment test using two approaches outlined in EPA's latest draft modeling Guidance for $PM_{2.5}$ (U.S. EPA, 2000). The first of these approaches is to develop a set of PM_{10}-component-specific RRF to use with UAM-AERO. In addition, a second approach, hot spot modeling using a point source model, will also be carried out.

EPA's draft modeling Guidance for $PM_{2.5}$ herein after referred to as "Guidance", suggests using a modeled attainment test, along with corroboratory analyses for a SIP attainment demonstration. We feel that it is appropriate to follow closely the methods outlined in the Guidance for the Utah PM_{10} SIP for the following reason. During a winter inversion, when PM concentrations reach their highest levels, 60% to 85% of the speciated filter mass is $PM_{2.5}$ or smaller. In this case the kinds of issues and uncertainties addressed in the Guidance will most likely apply to the Utah PM_{10} SIP. One difference between the approaches is that in the Guidance it is suggested that the design value be obtained by taking data averaged over three years to reflect the new $PM_{2.5}$ NAAQS. Since the PM_{10} SIP deals with, at most, two episodes during the same year, design values and RRF will be calculated from a single year and individual episode days.

The Guidance suggests dividing the monitored PM into six components:

"The modeled attainment test reflects $PM_{2.5}$'s nature as a mixture. This is done by dividing monitored $PM_{2.5}$ into its major components. In the test, these are

- mass associated with sulfates
- mass associated with nitrates
- mass associated with organic carbon
- mass associated with elemental carbon
- mass associated with primary inorganic particulate matter
- mass in a catchall category which includes unidentified measured mass and effects of unmodeled (e.g., external) sources of $PM_{2.5}$" (U.S. EPA, 2000).

To use the model results in a relative sense the ratio of the model's future to current predictions of the above components of PM_{10} will be used. Developing RRF requires the following five steps. It should be noted that the following procedure consistently varies from the Guidance where temporal averaging is involved. This occurs where suggestions are made to take an average of three years of data or taking an average of many days over multiple episodes. There will have to be an adaptation to these procedures because of data limitations. We recognize that this approach may not provide the insight that could be gained by looking at days with high concentrations under different meteorological regimes. We also recognize that with the high level of uncertainty associated with the model predictions taking an average of multiple data points would help to damp down some of that uncertainty. However, because of the data limitations discussed in preceding sections, episode selection and the modeled attainment demonstration are based on one episode during a five day period in February, 1996.

1. Determine the PM_{10} site-specific design value.

Because the RRF for PM_{10} is component-specific to the subset of six PM_{10} components, only sites with speciated data during at least one of the episode days will be used. For the episode February 11 - 15, 1996, the following monitors will have site and component-specific design values. (See the map at the end of this section for the location of these monitors in the modeling domain). For the 24-hr NAAQS the Guidance suggests computing the mean mass for each of the days modeled. The monitors which have two days of speciated data will be averaged.

Ogden	February 14 & 15
Washington Terrace	February 15
Bountiful	February 15
North Salt Lake	February 14 & 15
Beach	February 15
Magna	February 14 & 15
Air Monitoring Center	February 14 & 15
Cottonwood	February 15
Lindon	February 14
West Orem	February 14
North Provo	February 14

2. Calculate the component-specific design value.

As mentioned above the total mass of measured PM_{10} is divided into six components. The Guidance states that estimating the associated mass of each component from the measured species requires assumptions to be made about the stoichiometric relationships between the chemicals (U.S. EPA, 2000, ppg 74 & 80)[1]. The Guidance provides default assumptions for factoring each component in tables 3.4(a) and 3.4(b) which are reproduced below.

The estimated mean mass of each component is then divided by the total PM_{10} mass for each filter. This provides an estimate of component-specific PM_{10} composition. Finally, multiplying this fraction times the total PM_{10} mass provides the final site-specific design value for each component.

Table 3.4(a). Recommended Default Assumptions To Derive Mass Associated With Several Components of $PM_{2.5}$

(1) Component	(2) Formula To Derive Mass Associated With Component	(3) Assumptions
SO_4	4.125 (measured sulfur)	All elemental sulfur is from sulfate, & all sulfate is from ammonium sulfate
NO_3	1.29 (measured nitrate)	Denuder efficiency is ~100% & all nitrate is from ammonium nitrate
EC	1.00 (high + low temperature EC)	All high temperature carbon is elemental
OC	1.4 (organic carbon	Average organic molecule is 70% carbon (other elements include hydrogen and oxygen)

[1]"Stoichiometry is the branch of chemistry and chemical engineering that deals with the quantities of substances that enter into, and are produced by, chemical reactions." (http://www.chemistry.co.nz/stoichiometry.htm)

Table 3.4(b). Recommended Assumptions To Derive Mass Associated With Measured Inorganic Particulate Matter (IP) And Unattributed/Uncontrollable PM (U)

Component	Mass Associated With Component	Assumptions
Inorganic Particulate Matter (IP) = mass associated with crustal material (soil) plus combustion	Mass associated with soil = 2.2(Al) + 2.19(Si) + 1.63(Ca) + 2.42(Fe) + 1.94(Ti) Mass associated with combustion = oxides of remaining measured metallic elements	(Soil K)=0.6(Fe), FeO & Fe_2O_3 are equally abundant, a factor of 1.16 is used for MgO, Na_2O, H_2O & CO_2 Multiplication factors for remaining elements (associated with combustion) depends on the stoichiometry of the compound when combined with oxygen
Unattributed & unmodeled mass (U)	U = $PM_{2.5}$ - (SO_4 + NO_3 + OC + EC + IP)	Six components account for all measured $PM_{2.5}$, & unmodeled IP or OC is included in U rather than in IP or in OC

The next three steps are copied verbatim from the Guidance with $PM_{2.5}$ being replaced by PM_{10} and 65 Fg/m^3 by 155 Fg/m^3 in this document.

Step 3. For each site, develop component-specific relative reduction factors to be applied to the current site-specific observed design values derived for each component in step 2.

At each monitoring site, calculate the arithmetic mean concentration (using all modeled days in a quarter[2]) of each component corresponding with current emissions. Then calculate the arithmetic mean concentration of each component corresponding to the projected future emissions. For component j at site i:

$$(RRF)_{ij} = [(C_{j\ projected})/ (C_{j\ Current})]_i$$

where $(RRF)_{ij}$ is the relative reduction factor developed at site i for component j;

[2]Excluding "ramp-up" days

$C_{j\ current}$ is the predicted arithmetic mean 24-hr concentration of component j, computed from modeled days, using emissions which correspond to the period in which the design value is measured (e.g., [1996]);

$C_{j\ projected}$ is the predicted arithmetic mean 24-hr concentration of component j with projected emissions corresponding to a time two years prior to the required attainment date (e.g., 2010 for an area with a required attainment date of 2012). [In this case 2003 is the attainment date and since we are not using a three year averaging time for the NAAQS, the projected emissions period is the attainment year, 2003.]

Step 4. At each monitoring site, project future PM_{10} design values by multiplying each component-specific relative reduction factor obtained in step 3 times the corresponding component-specific observed design value derived in step 2. Add the results to obtain the estimated future site-specific design value for PM_{10}

This is done using the following expression

$(PM_{10})_{i\ projected} = [(PM_{10})_{i\ current}\ ]\ 3[(RRF)_j$ (Fraction of observed PM_{10} comprised of component j)$]_i$

where $(PM_{10})_{i\ projected}$ is the projected PM_{10} design value at monitor site i,

$(PM_{10})_{i\ current}$ is the currently observed design value at site i, and

$(RRF)_j$ is the relative reduction factor calculated for component j at site i.

Step 5. Compare each projected PM_{10} design value obtained in step 4 with 155 Fg/m^3.

If all of the projected PM_{10} design values are # 155 Fg/m^3 , the test is passed.

Using the RRF in the Modeling Domain

The Guidance recommends that each site-specific RRF be applied by taking the spatially averaged daily predictions in grid cells located "nearby" each monitoring site. The table below duplicates Table 3.5 in the Guidance and is the basis for our decision to use a 7x7 cell window around each monitor to apply the RRF.

Size of individual cell, km	Size of the array of nearby cells, unitless
# 5	7 x 7
> 5 - 8	5 x 5
> 8 - 15	3 x 3
> 15	1 x 1

Figure 7-1 depicts the grid cells which will be used for the site-specific RRF for each monitoring location. A number of things are evident in figure 7-1. The first is that the 49-cell windows surrounding each monitor have significant overlap in the two nonattainment counties. The RRF will be calculated using the *mean* value of the 49 cells surrounding the monitor, with that value being compared to the observed value. The values in the overlapping cells will be used as a part of the calculation of the mean value for each site-specific comparison.

Figure 7-1 also shows a significant number of grid cells in the nonattainment area which are not "nearby" to the monitor grid cells. One consequence is that the averaging windows (7x7 cells) do not extend far into the Wasatch mountain front and consist primarily of grid cells in the urban area. Conceptually, this is a benefit because most of the emissions are generated in the urban area and presumably get trapped in the valleys during a temperature inversion.

To account for grid cells in the nonattainment area outside of the averaging windows, the following technique is proposed as a screening measure. The nonattainment area is to be treated as two separate air basins; the Salt Lake Valley and Utah Valley defined by the County boundaries. This distinction is based on the results of the PM_{10} Scoping Study:

> By comparing the relative abundance of common geological species, aluminum (Al), calcium (Ca), iron (Fe), and titanium (Ti), it appears that the relative contribution of geological dust in Provo is twice as large as that in the Salt Lake City or Ogden. (In order to estimate the absolute contributions of geological dust in the future, it will be necessary to analyze teflon filters for silicon (Si), the most abundant crustal species.) This suggests that PM_{10} concentrations result from different emissions sources, such as potentially greater primary PM_{10} emissions in the Provo area, or different meteorological influences, which may result from the separation of Provo and Salt Lake City by the Traverse Mountains. (pg 3-11. Coe, etal. 2000)

It is proposed then, that the screening test be applied for the six component PM_{10} species in the following manner.

- In each nonattainment County select any grid cell with a current (1996) modeled concentration 20% greater than the highest concentration in any of the cells "near" a monitor.

- If no cells are found, the screening test is passed.

- If a cell, or cells, are found in either County create a 7x7 cell window around that cell to calculate a spatially averaged RRF.

- In Salt Lake County use the North Salt Lake monitor for the design value.

- In Utah County use the Lindon monitor for the design value.

- Multiply the the RRF times the design value for modeled attainment test for any selected areas away from the monitor locations. Use the results of the attainment test for these areas in the same way as is done for the areas near to monitor locations.

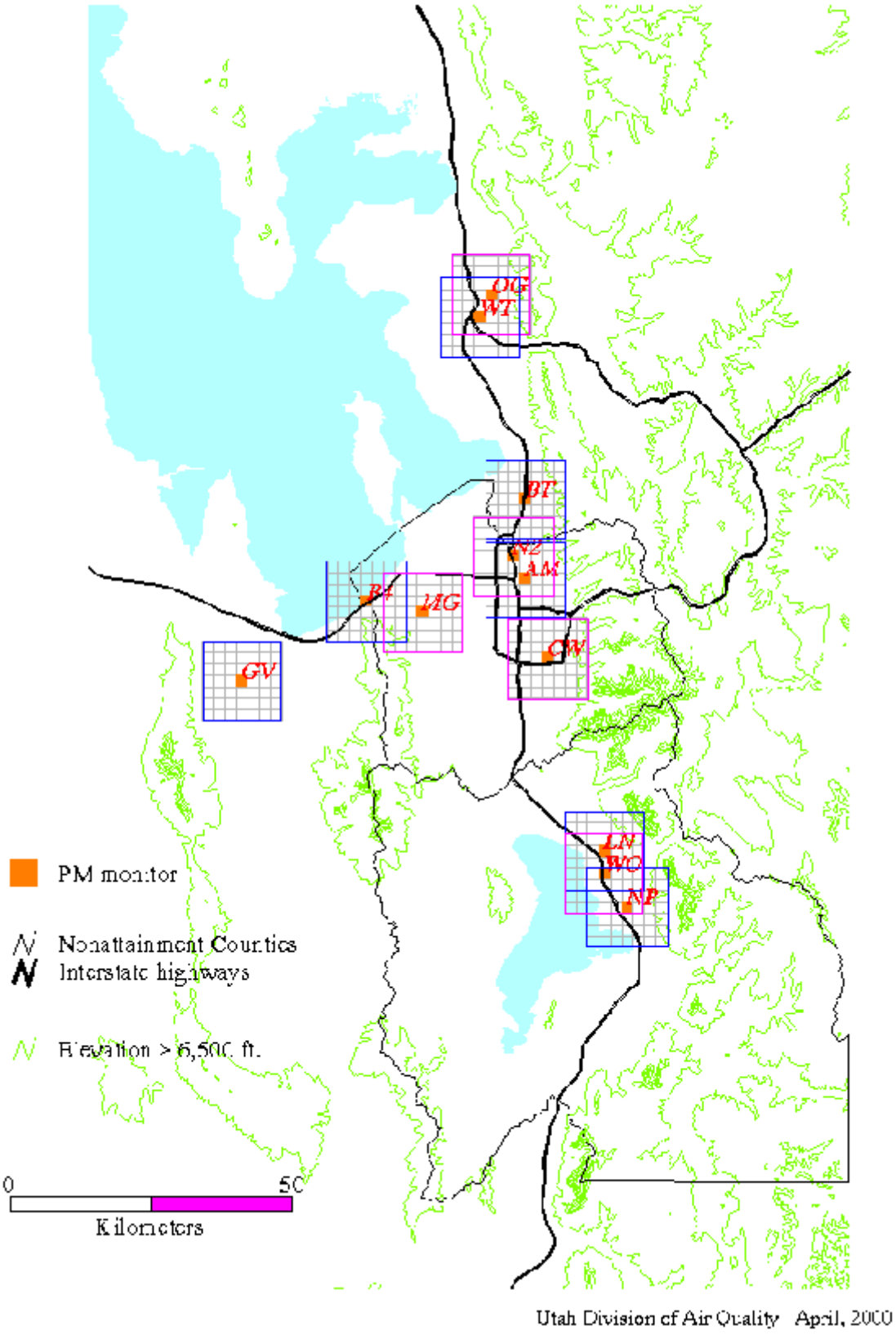


Figure 7-1. Regions Used for Site-specific RRF for Each Monitoring Location

7.3.2 Hot Spot Analysis

The modeled attainment test for PM_{10}, whether using a relative or absolute approach, has no ability to evaluate attainment at locations where there is no nearby monitor. Consequently, DAQ proposes to use a Hot Spot Analysis, similar to that discussed in EPA's "Guidance for Demonstrating Attainment of Air Quality Goals for $PM_{2.5}$ and Regional Haze" (Draft, March 27, 2000). DAQ recognizes that EPA's guidance document is specific to $PM_{2.5}$ but DAQ believes that this analysis will be robust for PM_{10} because the hot spot analysis relies on emissions of primary particulates which are often larger than 2.5 microns.

The hot spot analysis will focus on large sources of primary PM_{10}. Whereas secondary PM_{10} tends to be spatially uniform, localized areas of primary PM_{10} can be linked to particular sources of primary particulates. Consequently, we believe that the monitoring network can accurately represent secondary particulate concentrations, but there may be locations within the nonattainment areas that do not have nearby monitors which might have higher primary PM_{10} concentrations than the distant monitors represent.

In order to proceed with the hot spot analysis for the Wasatch Front nonattainment areas (Salt Lake County and Utah County) we will make a couple of initial assumptions. The 2-km x 2-km UAM-AERO grid will be aggregated into an 8-km x 8-km grid. This assumes that primary particulate sources impact an area greater than 2-km x 2-km. Since the hot spot analysis will be used in conjunction with the modeled attainment demonstration, we will use the 2003 emissions inventory which will be developed for the UAM-AERO future year modeled attainment demonstration. This inventory will include growth from 1996 to 2003 and will also include allowable emissions for the largest point sources.

The hot spot analysis will include the following steps:

- Evaluate the primary particulate emissions (from the 2003 future year projection inventory) in each 8-km grid cell in the nonattainment areas (Salt Lake County and Utah County) which has a PM_{10} monitor.

- Evaluate whether there are any grid cells within the nonattainment areas which do not contain a monitor and which have primary particulate emissions greater than those of any grid cell containing a PM_{10} monitor.
- Evaluate the emissions sources within those grid cells which have higher primary PM_{10} emissions than those in grid cells containing PM_{10} monitors. If there is a single point source within any of those grid cells which accounts for more than 50% of the primary PM_{10} emissions in that grid cell, then that point source should be flagged for a hot spot analysis. Because we are interested in achieving attainment by 2003, the emissions used for this analysis will be the emissions inventory which will be developed for UAM-AERO for the 2003 future year projection. We will also evaluate the domain for areas where there are multiple point sources within a single grid cell or that have high area or mobile emissions. However, preliminary review of the 1996 emissions inventory indicates that aggregation of area, point and mobile sources is very unlikely to trigger a hot spot analysis based on the above criteria.
- Apply a point source model to a flagged source for the month of February 1996 in order to demonstrate compliance with the 24-hour PM_{10} NAAQS. We are using this hot spot analysis in

conjunction with episodic modeling for two February 1996 episodes. Consequently, we want to represent hot spot impacts during this same time period relative to meteorology, operating conditions and emissions. We will use the highest 24-hour average concentration from February 1996 for evaluation of the 24-hour PM_{10} NAAQS. It is likely that CALPUFF will be the model of choice for this point source evaluation because CALPUFF can be used under stagnant wind conditions (which are present during February 1996).

- In order to evaluate the impact of the flagged source on the PM_{10} NAAQS, we must also evaluate the background primary and secondary PM_{10} in the grid cell of the highest hot spot impact. Since we are modeling a particular wintertime period using UAM-AERO, we will determine the secondary particulate component by evaluating monitored secondary PM_{10} in Utah and Salt Lake Counties during our two modeled wintertime episodes (in this case, February 6-9, 1996 and February 11-15, 1996). We are assuming that secondary particulates are relatively uniform throughout each air basin, so we will take an average of monitored secondary PM_{10} concentrations in either Utah or Salt Lake County (depending on whether the hot spot is located in Utah County or in Salt Lake County) during the episodes. This value for secondary PM_{10} will be added to the highest 24-hour concentration of primary PM_{10} obtained from the point source modeling. In addition, a background concentration of primary PM_{10} will be added to the above sum. The background concentration, in this case, will be obtained from monitored PM_{10} concentrations at Grantsville in Tooele County during February 1996. This site is likely to include typical background anthropogenic PM_{10} concentrations which are similar to outlying areas of Utah County and Salt Lake County.
- If the PM_{10} concentrations obtained from the above analysis exceed the level specified in the NAAQS (150 $\mu g/m^3$), then remedial measures are needed for hot spot point sources when designing future year control strategies.

7.3.3 Speciated Linear Rollback

In section 1.4 of this document, Overview of the Modeling Project, it is stated that due to significant uncertainties inherent in the aerosol modeling approach DAQ is prepared to supplement the UAM-AERO modeling study with an approach known as speciated linear rollback. This approach will be used in conjunction with UAM-AERO, if model performance is deemed acceptable. If model performance is such that it cannot be used with the necessary level of confidence to predict the effects of control measures on ambient PM_{10}, speciated rollback will be used by itself to analyze SIP control strategies. The remainder of this section describes the method which will be used to carry out this analysis. The methodology and approach described below comes primarily from the South Coast 1997 Air Quality Management Plan (SCAQMD, 1996), hereinafter referred to as AQMP.

The speciated rollback approach is a simplified method which assumes a linear relationship between the specific PM_{10} component emissions and the ambient concentration of those components on a chemically speciated air quality filter. Although it is known that for many of these PM_{10} components this type of linear relationship does not exist, the viability of this approach is deemed appropriate based on the following assumptions specified in the AQMP document.

(1) primary emissions (geological, primary organic, and elemental carbon) are generally unreactive, and linearity is reasonable;

(2) nitrate formation from NO_x, while not a linear process, is likely not far off from a linear approximation;

(3) sulfate formation is likely the most non-linear process, but since SO_x emissions are low at the outset, and are not projected to vary significantly over time, a linear assumption will not strongly affect the overall outcome; and

(4) secondary organics, as determined by CMB, represent a small fraction of the total PM_{10} mass, and hence errors in linearity assumptions will not significantly affect the overall outcome. (SCAQMD, 1996, p V-2-41)

Assumptions 1 and 2 are not tied to any particular modeling domain. Assumption 3 likely applies to the Wasatch Front as well as southern California because of the sulfur dioxide controls that have been put in place here as a result of the current PM_{10} SIP. While it is not known whether assumption 4 applies here, since there has been no recent chemical mass balance modeling (CMB) done for the area, the scoping study done for this project suggests that this assumption is not unreasonable:

[In the Utah PM_{10} nonattainment area] The largest contributions of EC plus OC were observed at sites located near population and industrial centers, which is consistent with the theory that these tend to be directly emitted. However, some fraction of OC also arises from secondary atmospheric reactions. EC plus OC contributed between 10-20 percent of total PM_{10} mass. (Coe, etal. 2000, p 2-9)

A fifth assumption is made based upon the limited data available for this analysis. A significant portion of the total PM_{10} mass is categorized as "unkown" and it is assumed that the majority of that fraction is geologic, crustal material or wind blown dust. The particulate filters are made of quartz which precludes the ability to measure silica. Since crustal material has a high level of silica the unknown portion of the PM_{10} will be classified as primary inorganic particulates.

As mentioned in 7.3.1 of this document, analysis in the Utah PM_{10} scoping study suggests that ambient PM_{10} concentrations in the two nonattainment counties are influenced by different emissions sources (Coe, etal. 2000, p 2-9). For this reason monitored PM_{10} values at two design sites, one in each county, will be used as the basis for future projections. The following outline describes the basic approach to be undertaken for this portion of the study.

- Divide the nonattainment area into two separate regions; Salt Lake County and Utah County
- Use the North Salt Lake monitor as the design site for Salt Lake County. This is the only monitor which exceeded the PM_{10} NAAQS during the February, 1996 episode with a total mass of 162 $\mu g/m^3$ on February 15th.
- Use the Lindon monitor, with a total mass of 147 $\mu g/m^3$ on February 14th, as the design site for Utah County.
- Use the tables from the $PM_{2.5}$ guidance document (U. S. EPA, 2000), reproduced in section 7.3.1, to calculate the mean mass for each of five PM_{10} components at the two design sites. See Table 7-1 for the five component species and the associated emissions category which will be used in the rollback.

- Use the rollback equation, below, to determine the level of reductions needed to bring the design sites within attainment of the NAAQS.
- Develop control strategies to meet the reduction targets based on the speciated rollback analysis.
- IF the UAM-AERO performance is acceptable, run the model with identified control strategies to corroborate the validity of the two approaches; UAM-AERO and speciated rollback.

The speciated rollback calculation as given in the AQMP and which will be used in this analysis is:

$$\text{Future Year } PM_{10} = \sum_{i} [((C_{i\ base} - B_i) * E_{i\ future} / E_{i\ base}) + B_i]$$

Where $C_{i\ base}$ = concentration of species i
B_i = background concentration of species i
$E_{i\ future}$ = future year emissions of species i
$E_{i\ base}$ = base year emissions of species i

Table 7-1. Component Species and Associated Emissions Categories Used in Rollback

Species	Emissions Category
Sulfates	Oxides of sulfur (SO_x)
Nitrates	Oxides of nitrogen (NO_x)
Organic carbon	Volatile organic compounds (VOC)
Elemental carbon	Diesel soot *
Primary inorganic particulates	Fugitive dust

* The emission factor, "remaining carbon portion" (RCP), from the PART5 model will be used to develop the emission inventory for diesel soot. Appendix A to the PART5 User's Guide defines RCP as "the remaining carbon portion (elemental carbon) of the exhaust particulate emission factor for a vehicle in class 'y' and of model year 'm'." Output from the PART5 model lists an RCP emission factor for each type of diesel vehicle. This emission factor will be multiplied by the portion of total county-wide vmt estimated to be driven by each diesel vehicle type. These values will then be summed for the total elemental carbon emission inventory for each county.

Background levels will be estimated for each component by using observed data from one of two sources. Either from an average of several IMPROVE monitoring sites located in a number of national parks representing fairly pristine areas, or from the DAQ air monitoring site in Grantsville, in the western portion of the UAM-AERO modeling domain. The decision as to which of these data sources to use will be made after further analysis of the data.

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APPENDIX A

Criteria for Initiating PM10 Episode Data Collection

Assumptions:

1. The Air Monitoring Center (AMC) requires 2 days to reconfigure the monitors to collect the PM10 data specified in the air quality action plan.
2. The desired meteorology consists of a high pressure system centered over the region for a period of five days or more.
3. University of Utah Meteorology Department's (Met Dept) extended forecasts are very uncertain beyond seven days but should be good for an early warning. A three-day forecast should be good for making a go/no-go decision.
4. In addition to the desired meteorology, the criteria for calling a PM10 episode consists of snow covered ground, high relative humidity, clearing index less than 100 and PM10 values of about 50 ug/m3
5. The modelers are looking for a PM10 episode that shows high (but not necessarily above the standard) values lasting for 3 to 5 days during a normal emissions period. They would like to collect data for about 3 periods, then select the best episode to complete the data/filter analysis.

Procedure:

1. The Met Dept will provide a short prognosis paragraph describing the meteorological forecast for the three-day and seven-day time frames to the AMC and DAQ contact list each Monday and Thursday.
2. The AMC and DAQ will review the University's prognosis to see if the long-range forecast indicates the potential for a PM10 episode.
3. The AMC and DAQ will review the University's next prognosis to see if the short-range forecast remains on track for a PM10 episode.
4. The AMC and DAQ will discuss a positive short-range forecast, and in conjunction with other criteria important for a PM10 episode will call a go or no go to setup for data collection.
5. Generally, the criteria will be interpreted loosely for the first episode then with increasing stringency as additional episodes are called (approximately three total).

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MONITORING PROTOCOL FOR 99/00 PM10 EPISODE

The PM10 study will be conducted on days when the meteorology is conducive to the accumulation of particulate matter in the lower levels of the atmosphere.

PM10 samples will be collected daily at the Cottonwood, Hawthorne, Lindon, North Salt Lake and West Valley. PM10 samples will be collected every third day at the Logan, Magna and North Provo stations. In addition PM2.5 samples will be collected daily at Hawthorne and Lindon and every third day at Bountiful, Cottonwood, North Provo, North Salt Lake, Ogden, Washington Terrace and West Valley. These filters will all be collected midnight to midnight to give a 24 hour average of particulate concentrations. The filters will be collected to determine mass concentrations of particulate matter. To determine particulate concentrations for shorter periods during the day, two sequential PM2.5 samplers are being converted to collect PM10 samples over 4 hour periods at Hawthorne and Lindon. All the filters will available so chemical analysis can be performed on the filters to determine the chemical content of the particulate matter collected. A PM2.5 "speciation" sampler will be operated at the Hawthorne station. This sampler will allow a wider range of chemical analysis of particulate mater than the other samplers.

Samplers that collect PM10 continuously and provide hourly average information will be operated at the Hawthorne, Lindon and Ogden sites. The same type of continuous sampler that collects PM2.5 will be operated at the Hawthorne and Lindon sites. These samplers will allow the evaluation of hourly changes in particulate concentrations.

Hourly data of gaseous nitrogen dioxide (NO2) and total nitrogen oxides (Nox) primarily nitric oxide (NO) will be collected at Bountiful, Cottonwood, Hawthorne, North Provo and Ogden.

Other measurements of ozone, ammonium and nitric acid will be conducted during the episode as resources allow.

Understanding and evaluating the meteorology during the periods that result in elevated particulate concentrations is very important, therefore, wind speed, direction and sigma will be collected at 21 sites during the study. Solar radiation will be collected at five sites.

Understanding the three dimensional aspect of the atmosphere is also essential. An accoustic sounder or SODAR will be operated during the study period. The SODAR will be located near a central valley location in Salt Lake Valley.

The attached "PM10 Study Chart" provides a convenient summary of the air monitoring that will be performed during the study period.

PM 10 STUDY CHART											
	PM10	PM2.5	Cont PM10	Cont PM2.5	NOX	NO2	PM2.5 Spec	Wind Speed Direction	Temp/ RH	SR/BP	SG/DT/PRE
Antelope Is.								X	BOTH		SIGMA
Badger Is.								X	BOTH	SOLAR	SIGMA
Beach								X	TEMP		SIGMA
Bountiful		THIRD DAY			X	X		X	TEMP		SIGMA
Cottonwood	DAILY	THIRD DAY			X	X		X	BOTH		SIGMA
Grantsville								X	BOTH		SIGMA
Hawthorne	DAILY	DAILY	X	X	X	X	DAILY	X	BOTH	BOTH	
Herriman								X	BOTH	SOLAR	DT
Highland								X	TEMP		SIGMA
Lindon	DAILY	DAILY	X	X				X	BOTH		SIGMA
Logan	THIRD DAY							X	TEMP		
Magna	THIRD DAY							X	TEMP		SIGMA
North Ogden								X	TEMP		SIGMA
North Provo	THIRD DAY	THIRD DAY			X	X		X	TEMP		SIGMA
N. Salt Lake	DAILY	THIRD DAY							NONE		
Ogden	DAILY	THIRD DAY	X		X	X			NONE		
Promontory								X	BOTH		SIGMA
Saltaire								X	BOTH	SOLAR	SIGMA
Spanish Fork								X			SIGMA
Syracuse								X	BOTH	SOLAR	SIGMA
Wash. Terr.		THIRD DAY						X	BOTH		SIGMA
West Valley	DAILY	THIRD DAY						X	TEMP		